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UNIVERSITY OF ILLINOIS

TRANSACTIONS
OF THE
ILLUMINATING ENGINEERING SOCIETY

FOUNDED IN LONDON 1909

INCORPORATED 1930

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VOLUME 21
No. 8 — 1956

32 VICTORIA ST
LONDON, SW1

Annual Subscription to Non-Members - £2.2.0
Price per Number to Non-Members - 5s. 0d.

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Lighting at London Airport

By J. G. HOLMES, A.R.C.S., B.Sc., F.Inst.P. *(Fellow)*

Summary

London Airport uses lighting extensively for the benefit of passengers, for the guidance and control of aircraft and for the maintenance of services. These three aspects are examined in detail, in terms of the requirements and appraisal of the results achieved rather than as a catalogue of designs or illumination levels.

Special lighting was required for the roads around and within the airport and particular requirements were stated for lighting the buildings of the central area in which the architect, the consulting engineer, the builder and the lighting engineer have collaborated closely. For aircraft guidance, the lights follow the international regulations, although in some respects those regulations have been written around the original installations at this airport. The hangar lighting is of a new order of magnitude, and permits comparison to be made between the standard blended type with localised sources and an installation of fluorescent tubing distributed over the whole ceiling.

(1) Introduction

The business of London Airport is the movement of people and goods and the interchange of information; a very human activity in which comfort and accuracy are pre-eminently important. It is a large-scale business, involving a working staff comparable in numbers with a medium-sized town and involving plant and equipment costing many millions of pounds. Lighting represents a considerable proportion of the electrical load of about eight megawatts as indicated by the load factor of about 75 per cent. The airport functions continuously, and in many of its activities full benefit has been obtained both from daylight and from artificial light by skilful design of the buildings in relation to the operations to be conducted in them.

There are three broad classifications of the lighting problems: for the movement of passengers, for the movement of aircraft and for the maintenance of services. In the first place, pleasantness of lighting must be combined with easy seeing; the lighting must be interesting without being conspicuous and efficient without being crude. Moreover, these requirements must be met without interfering with the operational activities of the airport. In the second set of problems, there are the more technical sub-classifications including the lights for the approach path, the airfield and the aprons, the lights for the control organisation including its signals and indicators, the screening of other lights and the inter-relation of visual and radio communications. The third classification is primarily industrial, including the lighting of hangars, workshops, offices and other spaces which are not particularly different from other engineering establishments.

London Airport has been conceived on a grand but not lavish scale, providing for the convenience and security of large numbers of people, and the lighting installations are, for the most part, in keeping with the scale and quality of the airport. This has not involved much in the way of new designs of lighting equipment, because satisfactory designs were already commercially available for many of the requirements, but over the period of years spent in the development of the airport a number of new methods of employing lighting have also been developed and these find their natural places in the present scheme. This paper does not attempt to catalogue the lighting fittings, nor to specify illumination levels, but rather to examine some of the requirements for lighting and to appraise the results that have been obtained.

The author is with Holophane, Ltd. The manuscript of this paper was first received on December 6, 1955, and in revised form on January 10, 1956. The paper was presented at a meeting of the Society held in London on February 14, 1956.

(2) The Lay-out of London Airport

London Airport occupies over four square miles between Hounslow, Staines and Colnbrook, some 15 miles west of London. It is bounded on the north by the Bath Road (A4), on the south and south-east by the Great South West Road (A30) and on the west by new roads connecting Stanwell and Longford. The temporary buildings along the Bath Road boundary were opened in 1946 and last December the Central Terminal Area was officially opened by H.M. the Queen. This Central Area, surrounded by six major runways and a network of taxi-ways and aprons and approached from the main road through a 700-yd. tunnel, was a notable advance in airport design. This is emphasised by the 120-ft. Control Tower projecting boldly above the flat landscape of the district and apparently encircled by approaching and departing aircraft.

The central diamond-shaped area comprises about 40 acres for buildings and passenger circulation, with another 100 acres (not yet all completed) of concrete aprons along its four sides. Connection with the Bath Road is by twin vehicle tunnels with pedestrian and bicycle subways, and there is also a series of vehicle and pedestrian subways making connection with the outer edge of the aprons, so that no vehicles normally cross either the runways or the aprons. Three pairs of runways run at angles of about $\pm$ 40 deg. and 90 deg. from north, each runway having its complement of approach lights (not yet all completed), threshold lights, runway lights, etc. Connecting these runways is a series of taxi-ways, extending from the aprons of the central area to the hangars in the two maintenance areas which are disposed to the east and south-east. Roadways run along the north side through the temporary buildings and around the perimeter to connect the maintenance areas.

Within the central terminal area, the control tower is to be surrounded by six buildings of which two are already completed: the passenger handling building along the south-east face and the airline-operation building at the eastern apex.

The nine years of operational experience before the opening of the central terminal area have been put to good use and a passenger or an employee cannot fail to be aware of good design in the layout, furnishing and lighting. There is excitement in the approach to the main passenger building either from the aircraft or from the road, and there is an atmosphere of restrained exhilaration in the main concourse, perhaps slightly muted by the more severe and serious Customs hall; in achieving these delightful effects, the architect and his advisers have used light cleverly rather than extravagantly, and in a very close integration with the structure of the buildings.

(3) Lighting for the Passengers

(3.1) The Approach Roads

Ordinary street lights emit a considerable intensity in directions near the horizontal and are not permitted in the vicinity of aerodromes because of the risk of confusing the pilots of aircraft or the officers in the control tower. Until recently, the official requirement for street lights near aerodromes was that they should give no light whatsoever above the horizontal: a neat and simple specification which erred on the side of safety but which could not be justified on technical grounds if proper account were taken of the light reflected from the road surface in near-horizontal directions. In 1951, therefore, the Ministry of Transport and Civil Aviation instituted experiments to determine how much upward light would be safe near aerodromes, and a specification was issued in 1952 based on the maximum permissible intensities given at the top of the next page.

The term "cut-off" has been applied to lanterns giving no upward light and the term "aero-screen" to lanterns giving a distribution on the lines of the above table.

Along the north side of London Airport, the Bath Road has cut-off mercury refractor bowl lanterns at the eastern end, installed in 1947 on posts sited suitably

Maximum permissible intensities for street lighting lanterns in the vicinity of aerodromes.

Angular elevation above horizontal (degrees)	Maximum intensity (candelas)
0	750
2	300
4	95
6	75
10	60
20	40
30	30
40	20
50	10
60	0

for high-angle sodium lanterns, and the effect is slightly patchy. Further west, several miles of cut-off mercury lanterns have been installed more recently with better results. Along the south side, there is very little main road lighting and one may wonder whether more or less upward glare is given by the dipped headlamps of vehicles on the Staines Road. Away from the roads adjacent to the airport, there is an increasing proportion of aero-screen lanterns, with both mercury and sodium lamps, giving good street lighting results.

(3.2) The Internal Roads

Within the airport boundaries, the lanterns along the north side are spaced rather irregularly according to the positions of the temporary buildings. These lanterns were installed some seven or eight years ago and yet they are closely similar in performance to the 1952 aero-screen requirements in respect of both upward and downward light; each consists of a deep prismatic bowl refractor with an opaque shield around the top of the bowl and about 2 ft. across, and takes a 400-watt horizontal mercury lamp. The newer lanterns for the main roads and parking areas are of the Group A cut-off type, and for the minor roads are of the Group B aero-screen type; this difference is not due to considerations of safety for the pilot, because both types are safe. but due to the requirements of the Control Tower. London Airport is liable to be misty, and vision from the Control Room would be seriously impaired if there were sufficient upward light from the road lighting lanterns to produce a veiling effect when looking across the airport at a level above the lamp posts. This calls for cut-off for the Group A lanterns which emit about 6,000 lumens each, but not for the Group B lanterns which are further away and which emit about 1,500 lumens each; it may be noted that London Airport was one of the first installations of Group B aero-screen lanterns.

Tubular fluorescent lamps are used for the Group A cut-off lanterns, three lamps being mounted under a white cover incorporating silvered-glass mirrors to form an axial beam distribution from the outer lamps with a useful peak at about 60 deg. Some 300 of these lanterns are used for the roads and car parks in the Central Area of the airport and the approach roads, for which the requirements are more of the nature of area lighting than street lighitng. In the flat treeless area, the 30-ft. poles are conspicuous but a cheerful colour scheme of yellow lanterns on blue poles of clean and simple design makes them quite acceptable. The illumination of the roadways is about 8,000 lumens per 100 linear ft. and of the parking area is up to 2 lm/ft^2, providing entirely adequate lighting by present-day standards.

The Group B aero-screen lanterns consist of a standard refractor-dome design

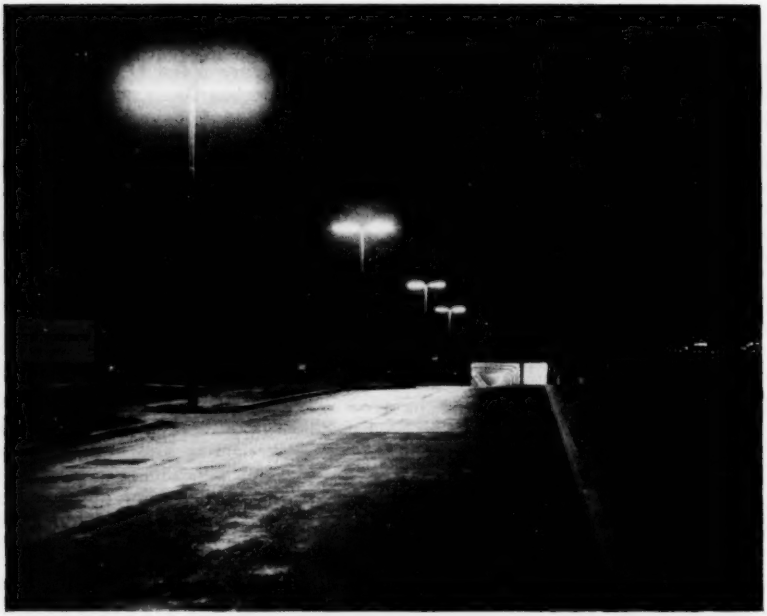


Fig. 1. Approach road from tunnel to central area.

with a single louvre mounted below the reflector; the downward light is not significantly affected and the lighting is of the normal Group B standard.

(3.3) The Tunnels

The two main tunnels and the subsidiary tunnels are all rectangular in section and are lit by cold-cathode fluorescent tubes behind patterned plate glass in fittings set in the upper corners. This gives a good distribution of light and freedom from glare, although the long lines of light seem to over-emphasise the surrounding walls. During the daytime, grading is obtained by employing almost continuous rows of 4-tube fittings at the ends of the main vehicle tunnels, then lengths of separated 4-tube fittings and then a length of more widely separated 2-tube fittings along the greater part of the tunnel. At night, only two tubes are lit in each fitting, to give an illumination similar to that on the approach roads, and no grading is required. The switching is automatic by a clock control, which also controls the lighting in the approach roads.

The tunnel lighting was the subject of considerable experimentation in one of the subsidiary tunnels and reasonably satisfactory results were achieved. It was found, however, that in scaling these results to suit the larger main tunnels the results have not proved entirely successful for bright sunny weather, and further work is now in hand to give more pronounced grading and higher illumination in daytime. The main tunnels are not long and they may be traversed in about a minute, so a driver's eyes have no chance to become adapted to low luminance levels; the grading at the entrance to each tunnel helps to reduce the shock of driving from perhaps 1,000 ft.

lamberts outside to about 2 ft.-lamberts in the centre, but it may be questioned whether grading is necessary at the exits.

As experiments are now in progress, no detailed description of the present installation need be given here. Attention is being given to the total light output from the fittings, the reflection factors of the ceiling and walls and the maintenance schedule.

It may be noted that condensation and exhaust fumes provide a severe test of the durability of any lighting fitting. In a tunnel of this length (about 700 yards) the temperature of the wall surfaces stabilises at the earth temperature, which is generally less than the air temperature; the air flow through the tunnel may be quite rapid and therefore severe condensation occurs, and alkali may be leached out of the wall surfaces and corrode the metal parts. Such alkali also hardens the atmospheric grease and dirt from the traffic. It follows that a highly resistant paint was found to be essential on the fittings and that very effective washing is necessary.

(3.4) The S.E. Face Building

The purpose of the "Passenger Handling" building, on the south-east face of the Central Area, is to provide for the wants of passengers from the moment of arrival at the airport by car or bus at the "land-side" of the building to the moment of departure to the aircraft from the "air-side," or vice versa. The routines associated with luggage, tickets, customs, passports and health are neatly handled by grouping the passengers in twelve "channels," which in broad principle are not unlike the platforms of a railway station (a comparison which flatters most railway stations); variations are made in this system to suit travellers on internal routes in the United Kingdom, travellers on overseas routes from or to this country and travellers from one country to another who alight at London Airport but do not officially enter this country. The pleasanter part of travelling has been given equal consideration; the banks, shops and enquiry desks, the baby corner, the restaurants and snack counters, the beer garden and the waving of handkerchiefs from the roof; the building has been sympathetically

Fig. 2. The Passenger Handling Building.

planned to cater as efficiently for these social activities as for the administrative routine. Light has been used to decorate and to create atmosphere as well as merely being an aid to sight, and it is obvious that the principal lighting effects were clearly visualised at an early stage in the design.

(3.4.1) *Reception Area*

One enters the S.E. Face building rather as a bee enters a hive, through a narrow slot at ground level into restricted spaces where routine has precedence over enjoyment. The ground floor has a ceiling height of only 7 ft., naturally lit in daytime through the double glass doors and artificially lit at all times by louvred filament lamp fittings fully recessed into a suspended sound-absorbing ceiling. The terrazzo floor and painted ceiling are light in colour but one is conscious of the concentration of light on the main task, to weigh one's luggage or to proceed up the escalator to the next stage of the journey. The effect of starting a journey has been achieved dramatically, but it may be a little difficult to read the small print on one's ticket, and, on several occasions, the staff operating the weighing machines have been known to insert cardboard labels in the louvres of the fittings to reduce the glare from immediately above them. Perhaps a little re-siting of the machines would be easier than changing the lighting. The trucking corridor, at the back of the reception area, runs the whole 160-yd. length of the building and is lit by open fluorescent trough fittings which give plenty of light, but the slight glare again emphasises the impression of being in the inner passages of a great building. The routine of reception is completed, the luggage disappears on a conveyor belt to reappear later in the Customs Hall, and the passengers proceed to the escalator and emerge almost suddenly in the exciting expanse of the main Concourse on the first floor.

(3.4.2) *Concourse and Restaurant*

The main passenger Concourse is undoubtedly the most impressive part of the S.E. Face building, combining the public amenities with the assembly points of the

Fig. 3. View of the main Concourse.

Fig. 4. Balcony and central staircase.

twelve passenger channels. One hundred and sixty yards long and 18 yd. wide, with the whole of one side glazed to its full height of 24 ft. by an enormous plate glass window wall and decorated at night by contemporary chandeliers, this hall uses light and space to ennoble the business of an airport terminal. The rear wall and the ceiling above it are white, illuminated by specially designed 300-watt indirect floods to provide the lighting along the back of the Concourse. The front part of the ceiling has an undulating chequer pattern of dark sound-absorbing panels and white plaster panels, lit by 5-ft. fluorescent tubes to provide the main lighting of this area at an illumination 5-7 lm/ft^2. Access to these built-in lamps is from above, by cat-walks amongst the roof trusses.

The central part of the Concourse forms a channel for spectators, visitors and those travellers who have time to spare, and it is treated differently. The ceiling above the escalators and information desks is dark grey, broken by a pattern of fully recessed 300-watt direct lighting fittings with obscured glass dishes, providing a rather higher illumination and more sparkle in the lighting than along the two wings of the Concourse. The same dark ceiling is continued over the stairs up to a balcony and to the restaurants and other rooms on the second floor at the back of the central channel; in this area, 16 plaster coves, 8-ft. diameter, have been formed in the ceiling to provide directional daylight through central tubular apertures and indirect lighting from concealed cold-cathode fluorescent tubes. These bold discs form a dominant feature in an otherwise dark environment, for the decoration and furnishings of the balcony are dark compared with the brightness of the Concourse itself.

In contrast with the indirect lighting employed almost exclusively in the Concourse, the gold coloured chandeliers along the line of the window provide a necessary sparkle and gaiety. These comprise sixteen trumpets, each with bare lamps at the mouthpiece and in the bell, grouped in orderly disorder around a central stem. These, like the

Fig. 5. Passenger Lounge and Restaurant.

other lighting equipment in the Concourse, were designed by the architect, and so there is a unity amongst the diverse patterns and light sources. The main indirect lighting fittings in the Concourse were, of course, constructed by the builder and required only lamps and holders from the lighting industry, and it is worth noting that this arrangement seems to have worked admirably.

The restaurants beyond the balcony are lit in the same way as many other functional rooms in this building, with recessed and louvred filament lamps. The outer louvre has generally been pierced to provide interesting high lights, and the louvres themselves have been finished white to provide a low-luminance diffused light beyond the fairly narrow limits of the direct light from the lamp. These fittings give little horizontal light and they leave the ceiling relatively dark, so that window reflections are not serious.

In the over-all scheme of lighting and decorating the Concourse, Balcony and Restaurant, the artistic effect was doubtless considered first, or before any questions of visual performance, and in this sense success has been achieved. There are, however, some difficulties, such as the highly polished metal treads of the escalator steps, which are so difficult to focus sharply as to become dangerous if one tries to see where the step is instead of feeling for it with the foot, or the area behind the main staircase on the balcony, where the only lighting comes from display windows and a telephone booth and where the dark green marble of the pillars and walls provides a difficult background for quickly recognising the friend one may have come to meet. Even the main staircase, with its admirably diffused natural or artificial lighting, lacks those shadows which normally define the nosing of a tread, and the pattern of light and dark grey marble again makes the eye less reliable than the foot. These criticisms are minor in character and should not be allowed to detract from the all-over effect of gaiety and space.

(3.4.3) *Customs Hall*

The visual task is probably more exacting in the Customs Hall than anywhere else in the building, and there was a requirement for good daylighting and good artificial lighting. Both have been achieved, the daylighting from a double-glazed monitor roof construction and the artificial lighting from continuous lines of 5-ft. 80-watt fluorescent lamps in open louvres running along the bottom of each glazed area. The luggage benches and the passengers are immediately below the higher parts of the monitor roof and thus between two lines of fluorescent lamps, providing a daylight factor of about 6 per cent. and artificial light of 10-30 lm/ft^2 in which the Customs Officers may make their inspection. The lighting is reasonably free from glare in spite of the dark grey walls and roof, the wine-coloured end wall and the lighter yellow floor, which reverse the usual arrangement of reflection factors. The double glazing of the roof is unusual and it was adopted to reduce both noise and heat loss, in which it seems quite effective.

The flow of the passengers through the Customs Hall is restricted to the appropriate "channel" and the luggage travels by conveyor belt through the same channel, making the transit of the passenger as easy as possible, but not comfortable or reassuring, and in great contrast to the liveliness of the Concourse or the peaceful order of the passport examination in the Immigration Hall. The Customs Hall has an unfriendly, institutional air to which the industrial type of lighting contributes; it looks as though it should be draughty and cold, with unpleasant inspectors and unhappy memories, which is an entirely unfair impression of the real state of affairs. Whatever one may think of the designer's decision to put the brightest lighting in such a mechanised environment, there is no doubt that the visual process functions at high efficiency.

(3.4.4) *The Immigration Hall, Health Control and Transit Lounges*

Between the Customs Hall and the air-side of the building there is a passport check in the Immigration Hall which is lit by two-lamp fluorescent fittings with egg-crate louvres, fully recessed in a fibre-board acoustic ceiling, giving 10-15 lm/ft^2. This is a quiet and well-lit space, with generous reflections between the rubber floor and the white ceiling, giving an impression of brightness in spite of rather poor illumination along the green-grey walls.

The Health Control rooms lie to one side of the corridors leading to the air-side waiting rooms. The corridors are rather dark, giving the same sort of impression as the reception area on the land-side, and are lit by a small number of recessed louvred filament lamp fittings.

The waiting rooms on the air-side are interesting because of their decoration and also because of the large continuous window giving the first view of the apron and landing area beyond the S.E. Face building. The same recessed louvred filament fittings are reinforced by indirect wall brackets giving a pattern of light on the columns and ceiling. Specially designed wallpaper, modern pictures on the dark brown and green walls, bright and comfortable chairs and a view of the always changing conditions on the apron combine to give these waiting rooms something of the same vitality as the Concourse.

The stages of the journey beyond the waiting rooms require few lighting fittings. There is a glass-sided corridor running the whole length of the air-side of the building, lit by close-ceiling opal units mounted directly on the wood-wool slab roof; this corridor is connected by bridges to the apron and also to the East Apex building, which has only been completed within the last month or two. The projecting opal bowls are quite suitable for such long corridors with a deliberately low illumination to permit gradual adaptation from light to dark or vice versa.

The S.E. Face building is a modern design with specialised lighting requirements, yet all these requirements were met by standard fittings, save only the ornamental

Fig. 6. Luggage Bay on air side.

chandeliers and wall brackets. Many of the fittings were of relatively recent design and others were built into the structure, but it speaks well for the lighting industry that satisfactory and acceptable designs were available.

(4) Lights for Aircraft Control

(4.1) Guiding Lights

Both radio and visual signals are essential to the pilot and neither can be regarded as subsidiary to the other. Both have been developed to a considerable complexity and are installed on a scale commensurate with the size and activity of the airport.

The lighting at London Airport conforms to the requirements of the British Standard "Guide to Civil Land Aerodrome Lighting" (B.S.1332 : 1952) and to the requirements of the International Civil Aviation Organisation, with a generous margin. This lighting system is used primarily for the latter stages of the approach and for control when taxying on the ground; it is required to operate at high intensity if the visual conditions are poor in daytime, as well as at a suitable level of intensity throughout the night.

(4.1.1) *Approach Lights.*

An airport beacon, consisting of a 7-kw. cluster of 36 green cold-cathode tubes, announces the identity of the airport by flashing the Morse Code letters VA at an intensity of 30,000 candelas; this is omni-directional and is therefore placed well away from residential areas.

The system of approach lights is that described by E. S. Calvert in his paper "Visual Aids for Landing in Bad Visibility," given to the Society in 1950; this system has since met with international approval and may be regarded as the most effective pattern for informing the pilot of the altitude of his aircraft and its position and direction relative to the threshold of the runway. The system comprises a single

line of lights, placed along an extension of the centre line of the runway and 3,000 ft. long, crossed by up to six horizon bars set at right angles to the centre line and at varying height and length according to their distance from the threshold.

In clear weather, low intensity omni-directional red lights are used, this colour having been chosen as the most distinctive. These fittings use a 250-watt bunch filament lamp in a red glass refractor, giving about 200 candelas of red light around 360 deg. in azimuth and a line of fifteen of these at 200-ft. spacing with two cross bars of 10 and 14 fittings is readily identified in clear weather.

For misty weather, higher intensities are necessary to achieve an adequate range of visibility, so directional fittings are used, shining towards the direction of approach. A variety of designs has been tried during the development of London Airport; there were the approach floodlights with a 500-watt bunch filament lamp in a paraboloid mirror and a spreading front glass, and others with a 1,000-watt linear filament lamp in a parabolic trough mirror, some of them on dimmer control. The sodium-lamp floodlight used for the horizon bars has a distinctive appearance and is liked by pilots, perhaps because of its wider beam spread and constant colour, but it cannot be dimmed satisfactorily. The most recent designs use 200-watt low voltage pre-focus lamps in paraboloid mirrors with some slight additional spread from the front glasses giving a white beam of about 80,000 candelas peak intensity with a spread of ± 3 deg. vertically and ± 11 deg. in plan, and capable of being dimmed in four steps from 100 per cent. to 1 per cent. intensity. This comparatively narrow beam is sufficient because of the accuracy and reliability of the radio guidance, and it may be noted that the combination of a really good system of approach lights with a sympathetic guide using the G.C.A. "Talk-you-down" technique has been found eminently successful, even in the worst conditions of flying at London Airport.

The two longest runways run roughly east and west and these have combined high- and low-intensity installations at each end, with white or yellow (sodium) lamps for high intensities and the omni-directional red refractor fitting for low intensities. The high-intensity systems comprise 10 groups of three fittings, 10 pairs and 10 single fittings at 100-ft. spacing, with six horizon bars consisting of up to 36 fittings mounted on gantries at heights up to 48 ft. above ground level. The fittings in the last 500 ft., nearest the threshold bar, are of a special light-weight type and are mounted at ground level to reduce the risk to aircraft. The details of the arrangements of the lights are varied somewhat to suit the other features of the site along the approach paths.

Low intensity systems are embodied in the pattern with the high intensity systems for the two east-west runways and are also provided at each end of two other runways, comprising a line of single fittings at 100-ft. spacing and with two horizon bars for the N.E.-S.W. runway and a line of fittings at 300-ft. spacing with a threshold bar only for the N.W.-S.E. runway.

These approach lights are used both in darkness and in misty daylight conditions, the latter requiring the highest intensities. The setting of the intensity control is largely based on experience combined with the meteorological visibility report, and it is under instantaneous control from the Control Room.

(4.1.2) *Threshold and Runway Lights*

The lighting fittings in the runways and taxi-ways at London Airport are nearly all of the "flush" type, sometimes known as "blister" fittings because of the shape of the exposed portion. The diameter varies from 12 in. to 16 in. and the projecting height from $1\frac{1}{2}$ in. to $2\frac{1}{2}$ in., although some of the taxi lights are smaller. Each fitting must be strong enough to withstand the impact of the tyre of a fully laden aircraft at touch-down or, no less severe, the maintained pressure of a stationary tyre at up to 300 lb. per sq. in. air pressure. The amount of the projection above ground, in terms of maximum height and volume of displacement of a pneumatic tyre, must not

be such as to cause any significant shock to the undercarriage of an aircraft. There are the other hazards of snow ploughs, tracked vehicles, hard stones embedded in vehicle wheels, and also great reliability is required in all weathers.

Light emitted at angles greater than about 10 deg. above the horizontal is generally of no value whatsoever, because a pilot does not look down at this angle, and the maximum intensity should be directed at 2 deg. to 4 deg. above the horizontal to achieve the best utilisation. In most parts of the landing area, the light need only be directed along the line of the runway, within a few degrees of spread in the horizontal sense. It is a matter of some difficulty to obtain a high-intensity beam ± 5 deg. wide and at only 3 deg. elevation from a nominally flush fitting, but details of optical designs have been published elsewhere.

The threshold lights form a green bar across the beginning of the paved runway, to mark the end of the centre line of the red or white or amber approach lights and to mark the beginning of the two lines of runway lights between which it is safe for an aircraft to land. The middle part of this threshold line consists of flush fittings, which give intensities of the order of 1,000 candelas of green light and are mostly of the type described by H. J. Turner in the paper "The Design of Contact Lights for Aerodrome Runways" given to the Society in 1949. The light distribution is bi-directional, so that the far end of a runway is marked by a green bar as well as the threshold.

The outer ends of the line also consisted of flush fittings until recently, but elevated lights with 100-watt lamps and paraboloid mirrors in light-weight fittings are now used to give higher peak intensities, more comparable with the approach lights.

The runway lights are mostly of the same type as the flush threshold lights mentioned above, giving white light with a peak intensity of about 5,000 candelas at 4 deg. elevation. They are set in two lines 150 ft. apart and spaced at 80-ft. intervals along five of the runways, amounting to nearly 1,000 fittings, each with its own separate transformer and each carefully focused and directed within an accuracy of about ± 1 deg. The lights at the end sections of each runway give yellow light rather than white so as to give the pilot some indication of his position along the length of the runway; an interesting experiment now in progress is the use of short stub bars of elevated high-intensity lights, similar to the elevated threshold lights mentioned above, at the west end of No. 5 Runway acting as an extension of the approach light system.

There is another group of elevated lights near each end of the main runways, to indicate the run-up positions for aircraft before taking off. These are low-intensity omni-directional dome refractor fittings with blue glasses and 36-watt lamps, giving about 10 candelas of blue light.

In general, flush lights have been chosen in preference to elevated runway lights for several reasons, including safety, and having regard to the 300-ft. paved width of the runways. Elevated lights would give a higher intensity and would be less affected by snow or dirt, but such lights must always be regarded as expendable and cannot be mounted in the paved runway. Aircraft such as the Convair, with less than 12 in. ground clearance at the tips of the propellers, might make an elevated light very expensive indeed, and snow ploughs and vehicles of all sorts seem to be attracted by a row of fittings with a frangible mount and a collapsible body. Current developments in flush lights are likely to yield higher beam intensities from fittings with less projection, and the present policy of using such lights at London Airport is likely to be confirmed.

The pilot who has followed the line of approach lights at night and has crossed the threshold bar finds that he must touch-down on unlighted concrete, guided only by lines of lights about 75 ft. away to port and starboard, and E. S. Calvert has shown that under these conditions his sensitivity to change of direction is not high in misty weather. Developments in centre-line runway lights may, therefore,

be watched with great interest, but none of these fittings has as yet been installed at London Airport, nor at any civil airport in this country.

(4.1.3) *Direction Lights, Taxi Lights and Stop Bars*

Once on the ground at night, the pilot has little to guide him in finding his exact position on the airfield, apart from his experienced knowledge of such surrounding buildings as he may be able to recognise. It is, however, important that he should be guided to the apron in the terminal area by the correct route and that he should be protected from other vehicles and taxying aircraft; the system of runways and taxi-ways at London Airport is controlled by two methods, for use by day and by night respectively, as well as by radio instructions from the Control Tower.

In daytime, the ground traffic of taxying aircraft is controlled by elevated route indicator boards at each junction of taxi tracks and of runways, with white lamps as a GO signal indicating which route is to be taken and red lamps as a STOP signal. These are manually controlled and will be interlocked with the system of taxi lights and stop bar lights used at night, and they lead an aircraft from the runway to the right apron or vice versa. There are no traffic signals of the ordinary red-yellow-green type in London Airport except for road traffic on some of the service roads.

Along one side of each runway and along the centre of each taxi-way there is a line of green flush lights set at 80-ft. intervals. Some have glass domes and some have cast iron tops with a ring of glass, as in the fittings described by H. J. Turner mentioned above, or by S. English in the Proceedings of the Society's Convention in 1946. The light distribution is symmetrical in plan and, with a 36-watt lamp, an intensity of about 30 candelas of green light is given at 5-8 deg. elevation.

The runways and taxi-ways are divided into blocks, varying in length from 300 ft. to 1,800 ft. and defined by stop bars of red lights set at the sides of runways and across the taxi-ways. These lights are similar to the taxi lights in all respects except colour, and together they amount to some 4,500 fittings controlled in over 700 electrical circuits.

(4.2) Apron Floodlights

The aprons around the terminal area are about 500 ft. wide and lighting has to be provided for a variety of activities, including the movement of passengers and luggage as well as the more technical requirements for the aircraft. In many airports ordinary floodlights have been modified with a few louvres and placed as high as possible on the terminal buildings, giving a unidirectional light which dazzles the approaching pilot and casts long shadows. Floodlight towers on the air-side of the apron have usually been forbidden as too dangerous or too inconvenient. At London Airport, 60-ft. towers have been erected on the land-side and air-side of the aprons and seven or nine special 1,000-watt floodlights are mounted on each.

The requirements for light distribution are exacting, to avoid both dazzle and excessive upward light which might interfere with vision from the Control Tower and yet to provide a uniform illumination of about 1 lm/ft^2 over the apron surface. The specification called for a high intensity with a wide spread in plan and a sharp cut-off vertically to less intensity than an aero-screen street lamp; it was found that the louvres necessary to control the upward light were almost equally effective in reducing the downward light, and it was necessary to adopt an asymmetric pattern of spreading flutes on the front glass to provide light nearer the base of the tower and to avoid patchiness. The production of a floodlight weighing only 25 lb. and giving 35,000 candelas with a beam spread of $\pm$ 20 deg. horizontally, about 10 deg. upward and 20-25 deg. downward from a 1,000-watt 16,000 lumen Class B2 lamp, is one of the advances in lighting practice that have been initiated by the needs of London Airport and achieved by collaboration between the Air Ministry and the lighting industry.

(4.3) The Control Building

At the centre of the diamond-shaped Central Area, the nine-storey tower of the Control Building is a prominent landmark of London Airport. In the two-storey wings, the telecommunications equipment and the administrative offices of the Airport are grouped with a medical section and staff amenity rooms. The tower is floodlit, partly as a spectacle and partly, perhaps, to act as an obstruction light.

(4.3.1) *Administration Offices*

There are three basic types of lighting fitting, the opal bowl or shade, the recessed louvred filament fitting and the recessed louvred two-lamp fluorescent fitting, and these are used fairly generously as appropriate in offices, corridors, teleprinter rooms, medical rooms and so on.

Many of the fluorescent lighting fittings incorporate ventilation and heating outlets, which mar their appearance when they get dirty but which do not appear to affect the efficiency of the lighting.

The staff cafeteria has indirect lighting from 5-ft. fluorescent lamps set in structural troughs running across the 70-ft. width of the room, enlivened by zig-zag lines of holes drilled in the underside of the trough and by one wall of specially designed wallpaper with indirect wall brackets. The central servery is brightly lit with louvred reflector fittings and the general effect is interesting and pleasant, although the absence of any acoustic treatment on the ceiling does not make for a restful meal.

In the room devoted to relays and racks for the airfield lighting, special fluorescent lighting has been adopted. This comprises parabolic trough mirrors of anodised aluminium, each with a single lamp, mounted immediately over each rack but tilted so as to shine on the vertical face of the adjacent rack. There is some glare and the diversity factor is large, but the working illumination of 10-30 lm/ft^2 on the vertical plane has been achieved with a relatively low power consumption.

(4.3.2) *Control Room Lighting*

The two-storey Approach Control Room, on the sixth and seventh floors, contains the radio-telephones and radar screens by which the controllers keep in touch with aircraft up to 60 miles from London, working almost entirely through the telecommunications system in spite of the generous provision of inclined glazing in the projecting windows. Much of the work is done by the light of desk lamps, aided by specially controlled fluorescent fittings. These will doubtless be discussed more fully in the papers by L. Knopp, S. T. Henderson and R. D. Nixon, to be presented to the Society in April, 1956, and need not be described here.

The Aerodrome Control Room, on the roof of the tower, provides an unobstructed view of the whole airport. The tilted windows are double glazed, with tinted heat-absorbing plate glass for the outer component and with heating of the interspace to prevent condensation. The ceiling is dark blue and the louvred recessed lighting fittings are rarely used because in spite of careful design there are some reflections to be seen by a seated person. Desk lights can be used safely because they are below the level of reflection, and for this purpose long opal lamps have been enclosed in adjustable tubular shades so that the amount and direction of light are immediately controllable.

(4.3.3) *Control of Airfield Lighting*

The electrical circuitry is too complicated to be discussed here, but the results are of some interest. Most of the information received in the Control Room comes by telephone or visually from the airfield; for use in misty conditions a radar screen shows a plan of the airfield in great detail, being sufficiently sensitive to show a contact light projecting 2½ in. above a runway and sufficiently accurate to enable a controller to recognise the type of aircraft by the shape of the trace on the

screen. With this information the controller must receive and despatch aircraft and move them about on the network of runways and taxi-ways, using radio or the taxi lighting system to communicate his instructions.

All the signal lights and guiding lights of the Airport are controlled from this room, including 64 circuits of approach lights and 768 runway and taxiway circuits. These lights are reproduced on a mimic diagram mounted conveniently below window level on the east side of the room but the control switches cover a range of panels extending around nearly half the periphery. A coded pulse system is used, so that when a switch is turned the relays are selected and operated, the lamp is energised and the flow of current is reported back to the Control Tower by the appearance of a light on the mimic diagram and the extinction of a light on the switch board with a delay of not more than two seconds. Separate keys are used for selecting the pattern of lights and for selecting the intensity level. For the taxi lights, the green centre lines and the red stop bars are electrically interlocked in each block, but otherwise the blocks are individually controlled.

In this control of the lighting pattern great reliance is placed on the human element. There is to be automatic scanning of the electrical apparatus to detect faults and there is almost instantaneous response to any adjustment of a switch, but the selection of the pattern of lights is at the will of the controller rather than being governed by elaborate electrical interlock systems or by a programme calculator. This provides the flexibility needed in a growing airport with rapidly changing conditions of weather and traffic, but, more importantly, it provides certainty that information has been correctly transmitted to the aircraft without any doubts regarding the self-checking properties of automatic equipment. Throughout the lighting installation on the airfield and its approach, the equipment has been made as reliable as possible, but the detailed setting-up of the patterns required is the responsibility of the controller.

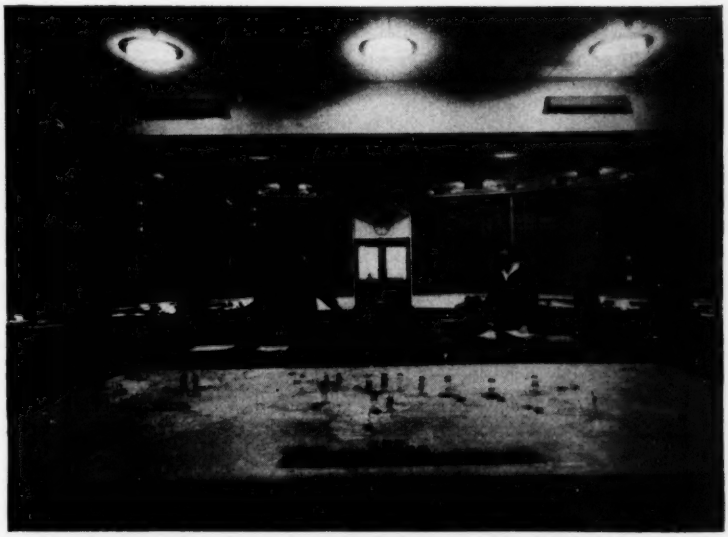


Fig. 7. The B.O.A.C. Movement Control Roo.n.

(5) Hangar Lighting

The two main hangars are in No. 1 Maintenance Area on the east side of the airport and are used by the B.O.A.C. and the B.E.A., both for aircraft maintenance and for office accommodation. The features to be discussed here are the lighting of the hangar pens and the workshops, which differ in several respects from ordinary industrial lighting.

(5.1) The B.O.A.C. Hangar

The whole building is 850 ft. × 430 ft. and 100 ft. high, including four hangar pens at the corners, each 330 ft. × 140 ft., to take three aircraft of the Stratocruiser size. The building is notable for its long concrete cantilevers of 75-ft. span carrying portal girders 150 ft. long, with enormous folding doors for the hangar pens so that the whole of one long side of each pen is free from obstructions.

The natural lighting of the pens is generous and the glass area is almost equal to the floor area, although somewhat obstructed by the complex concrete girders in the roof. The artificial lighting follows the practice of other London Airport and R.A.F. hangars, using blended mercury and tungsten light from pairs of two-lamp fittings with 1,000-watt filament and 400-watt mercury lamps in translucent reflectors at 50-ft. mounting height, to give 20-25 lm/ft^2. The results seemed very satisfactory and free from coloured shadows, although the pairs of twin fittings were arranged in parallel symmetry instead of the better diagonal symmetry. A clean concrete floor helps to give good illumination on the underside of the wings and fuselage, and values are up to 15 lm/ft^2 at these points.

The Engineering Hall of the B.O.A.C. building, roughly 800 ft. long × 100 ft. wide, has daylight from its glass roof along a smali part of its length, the principal illumination bejng by cold cathode lamps laid along the roof trusses and on the underside of the fourth floor at 45-ft. height, giving 20-25 lm/ft^2. The roof structure provides

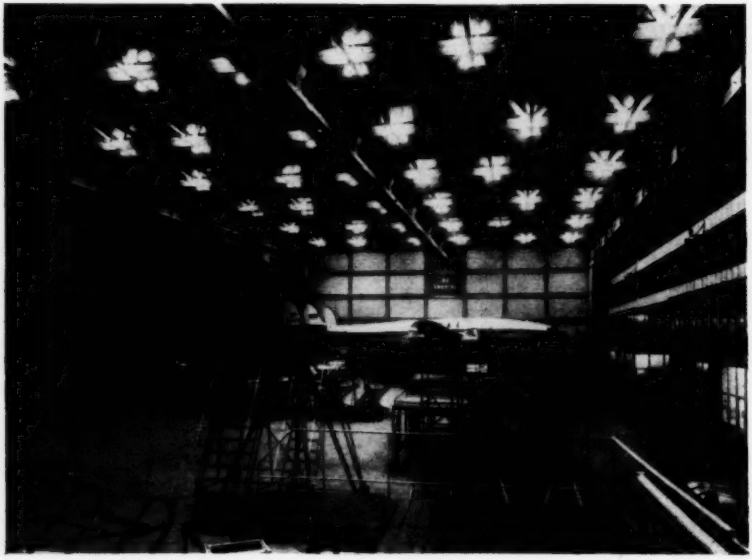


Fig. 8. B.O.A.C. Hangar.

a louvred effect, and a pleasantly glare-free effect is obtained with good diffusion. Local lights are provided on most of the machine tools and benches to give directional light at a higher illumination necessary for fine work.

In the Radio and Instrument workshop on the fourth floor, over one end of the main engineering hall, good natural lighting is again provided through a laylight of figured glass set in heavy concrete beams, which act as louvres. Fluorescent lighting was not permissible because of the interference risk, and therefore 300-watt tungsten lamps were used above the panels in the laylight, translucent reflectors being specified to reduce the obstruction of natural light, giving 25-30 lm/ft^2. It is interesting that these 300-watt lamps are free from glare even at about 11-ft. mounting height, because of the shielding by the roof structure.

The B.O.A.C. Movement Control Room, set within the building and artificially lit at all times, presents an unusual lighting problem. The room is horseshoe-shaped and the controller at a central desk is surrounded by dark green chalk boards from desk height to ceiling, recording or indicating the many thousands of messages received or sent each day. Uniform luminance of these boards has been achieved by directional lenticular fittings, set flush in the ceiling and shining obliquely downwards; although the system seemed free from glare, a controller looking at these boards for many hours may become unusually sensitive to glare, and special precautions have had to be taken to screen the scattered light from the lens prisms and to use matt-surface paint. The controller's difficulties are emphasised by a large ventilation duct, running over the central desk and casting a certain gloom over it, which lowers the adaptation level of the controller's eyes to somewhat below the 35-40 lm/ft^2 illumination level of the chalk boards.

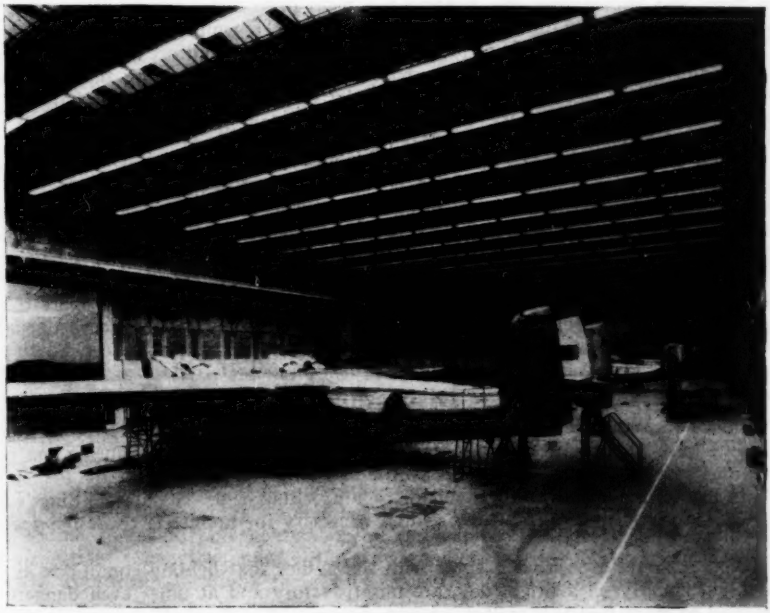


Fig. 9. B.E.A. Hangar.

(5.2) The B.E.A. Hangar

The main hangars in the B.E.A. building also represent a large area which has to be lit from 40 ft and here cold-cathode tubing has been used in simple reflectors mounted directly on the underside of each of the main beams. The extent of the installation is 1,950 fittings, each with four lamps 10 ft. long, which was large enough to justify the production of a special colour, known as "Airport White," for the fluorescent lamps. It is a pleasant colour and the lighting is reasonably shadowless because there is no louvre effect. This wide diffusion helps the illumination on the downward surfaces of an aircraft and a representative value is 12 lm/ft^2 compared with 18-20 lm/ft^2 direct illumination on the floor.

(5.3) Comparison of Blended and Tubular Fluorescent Lighting

The two types of installation in the B.O.A.C. Hangar and the fluorescent lighting in the B.E.A. Hangar permit a direct comparison of these two methods at about the same level of illumination. Such comparison must, for the present, be subjective and personal. The author found the cold-cathode installation more pleasant because of its diffusion, low contrast and good colour; on the other hand, the blended installation seemed better to work under because of its greater directional character, its higher contrast and its firmer shadows. Colour rendering and daylight blending were adequate in both types and flicker was negligible, being rather less under the blended installation. No comparison of costs or of power consumption has been made.

(6) Conclusion

One cannot fail to notice and to be interested by the lighting at London Airport. The terminal buildings use light as a means of decoration, even in daytime, and the attractiveness of the landing area at night lies largely in its multicoloured scintillation. This paper has shown that this lighting has been done well, subject, of course, to different criticisms from different people, and that the ingenuity and effectiveness of the lighting makes a valuable contribution to the safety and comfort of the passengers. As radio and other equipment become more elaborate, so the lighting that goes with them becomes more elaborate and indispensable; it will be a continuing challenge to lighting engineers to enable the human eye to maintain its status amongst all the electronic and automatic equipment of modern aviation.

(7) Acknowledgments

The author is indebted to the Air Ministry (C.M. & E.E. Division) and to the Ministry of Transport and Civil Aviation for great courtesy and helpfulness in providing information, and to the architect, the consultants and numerous friends in the lighting industry who have provided data and photographs of lighting equipment and installations, without which this paper could not have been presented. The views expressed in the paper are, of course, the author's personal responsibility. Thanks are due also to the Editors of several journals for permission to use photographs.

Discussion

MR. C. S. WHITE: This excellent paper has been particularly interesting to me because I have visited the Central Area on a number of occasions during the past 12 months and have been impressed by the skill displayed, not least by the architects, in the selection and arrangement of lighting equipment. Standard fittings have improved enormously and it is now seldom necessary for architects to design special types.

From personal experience I agree with the author that lighting conditions in the tunnel, particularly on a bright day, are unsatisfactory and at times even dangerous. I am glad to learn that this matter is under review.

The author mentioned the "black hole" on the threshold of the dual runway-

lights. Could he tell us what system is in use in the United States and if we have anything to learn from American practice.

MR. A. G. PENNY: I have used London Airport on many occasions and would like to speak as a user. One's impressions as a traveller begin at the Waterloo Air Terminal which though not designed for its present purpose serves that purpose quite well. One's impressions on arriving at London Airport are disappointing, the low ceiling of the reception area, for instance, has a depressing effect. On reaching the main concourse one again cannot help but be disappointed that through the vast windows one can see only the car park; any indication of air travel is absent. After the harsh factory-like illumination of the Customs hall the transit lounge seems very dark.

On the whole the integration of lighting and decoration has been very well done, but I do not think it gives travellers the impression that they are about to embark on an air journey.

DR. D. TURNER: I have had an opportunity of observing the lighting in the passenger handling building and have got the impression that insufficient thought was given to ensuring that adequate illumination was provided for persons working in the building. In the immigration hall, for instance, where there is no natural light, the illumination on the desks where officials scrutinise passports varies between 6 and 19 lm/ft^2. In the health block the lighting is very poor, the illumination in consulting and treatment rooms being 3 lm/ft^2. There seems to be little provision for supplying sources of local lighting in either place.

MR. R. L. C. TATE: In the main concourse one gets the impression of spaciousness and grandeur, largely because of the lighting. Unfortunately there is no lighting on the information board.

MR. D. C. SMITH: The author has told us that little thought seems to have been given to maintenance of the lighting, and that in the case of the cold cathode fittings in the main concourse access to the lamps can only be gained by erecting scaffolding over the stairs. Could he say how lamps are changed in the decorative fittings ("Christmas trees") in the main concourse.

MR. E. S. CALVERT: Although the terminal building and its lighting are attractive and efficient, it is a pity that the main lounge looks out on the car park instead of on to the runways and marshalling areas. Many people find it fascinating to watch aircraft land and take off, particularly at night, and as passengers often have to wait for long periods at airports, I think it very desirable that they should have something interesting to look at. The building at Washington Airport is an illustration of the kind of thing I have in mind.

Another speaker has mentioned the question of better runway lighting patterns, and has suggested that we might have something to learn from the United States on this. I would like to make it clear that much more work has been done on improved patterns in this country than in the United States, for the simple reason that we are the only country that has succeeded in building a landing simulator which is realistic. This simulator is now being used intensively to find the best pattern for the new runway at Gatwick. Unfortunately, once a runway is made, little can be done to improve the pattern, so this work is mainly applicable to new runways. I would also like to add that, thanks largely to Mr. Holmes, we now have a type of runway light which is suitable for installation in the touch-down area of the runway. This gives about 8,000 candelas and is of very small size, the projection above the runway surface being only $\frac{1}{4}$ in. This fitting has been installed experimentally along the centre line of a runway for about a year, and, so far, there has been no damage to either fittings or aircraft.

Finally, I would like to emphasise the fact that our work on visual aids has

paid very handsome dividends in safety, regularity of service, and airport utilisation. An example of this is the fact that in a visibility of half a mile the failure rate in first attempts to land is less than 2 per cent. at London. In the United States the failure rate is usually over 30 per cent. in this visibility, although it has improved recently because of the introduction of better instrumentation in the aircraft.

MR. HOLMES (in reply): The comment by Mr. White on the lighting in the main tunnels is undoubtedly justified; there is not enough light in daytime, even if the fittings were really clean, and the low reflection factors of the roof, walls and road surface effectively quench the inter-reflection of light which is such a great help in a properly painted tunnel. Perhaps this miscalculation can be associated with the vehicle speeds, which are supposed to be limited to 15 m.p.h. by the written regulations, or to 30 m.p.h. by the displayed signs, but which are generally up to 50 m.p.h. in practice. Dark adaptation would not help much in the 45 seconds taken from the entrance to the middle at a speed of 15 m.p.h.; there is very little adaptation indeed in the 15 seconds taken to reach the middle at a speed of 45 m.p.h.

Mr. Penny has spoken as a user of the passenger building, and I entirely agree with him that, from the moment of entering the low doorway to the time of reaching the dark transit lounge, one is not conscious of the air outside. Lighting and decoration have been used to make the building interesting in a rather self-contained way and it might almost as well be a subterranean building as an aerial building.

Mr. Turner has perhaps generalised too widely from his observations in the immigration and health control sections. For these sections, his comments are fully justified, and he might also have referred to an office used for clerical work in which the average illumination is below 2 lm/ft^2, or to the floor heating in the Customs hall, which discomforts the inspectors more than it comforts the passengers. There may have been some change of use of some of these rooms; for example, the consulting and treatment rooms may have been intended for resting only, but the present arrangements in many of the subsidiary rooms in the building are not satisfactory.

Mr. Tate's comment on the unlit information board would doubtless have been stronger if he had seen it recently. Instead of being edge-on to the window it now has its back to the window and it lacks direct illumination by day and by night. Perhaps it is not yet in its final position.

The arrangements for maintenance of the lighting in the concourse, mentioned by Mr. Smith, are very good, with top access for the chequered part of the ceiling and with raising-and-lowering gear for the chandeliers. The access to the cone lights over the main staircase is only possible by scaffolding and a simple calculation of sixteen cones each containing nine specially made lamps quickly demonstrates the value of group replacement.

Mr. Calvert is eminently qualified to speak about runway lighting patterns and he has replied with authority to Mr. White's question. I appreciate his reference to the new runway surface fittings which are installed at Honington, but for which no provision has been made at London Airport. It is quite clear to me that some additional visual guidance is very desirable in the "black hole," on which a pilot has to touch-down after passing the last of the approach and threshold lights, and it may be noted also that current trends lead towards flush lights rather than frangible elevated lights for the last section of the approach system. The problem of getting a beam of many thousands of candelas emitted horizontally from a fitting of zero projection has no solution, but there is a compromise between these conflicting requirements, and I think a horizontal beam from a shallow fitting is better than an elevated beam from a flush fitting. These are not yet provided at London Airport, however, and I will not develop the subject here.

Symposium on Screen Viewing

(1) The Viewing of Cinema Screens

By LESLIE KNOPP, M.B.E., Ph.D., M.Sc., F.R.P.S. *(Fellow)*

Summary

This paper discusses the viewing of screens in commercial cinemas where the screens are of the reflective type and the light sources are carbon arcs.

(1) Screen Luminance

At the International Standards Conference held in Stockholm in June, 1955, it was agreed that a proposed international standard be prepared for the luminance of screens and that this proposed standard be based upon a nominal screen-luminance of 35 nit,* with minimum and maximum values of 30 and 50 nit respectively. These determined values refer only to matte screens and relate to measurements at the centre of the screen, taken from any seat in the auditorium. It was further agreed that the minimum value of luminance at the edges of the screen be 65 per cent. of the value of luminance at the centre of the screen. These points of measurement were defined as being in the horizontal axis at a distance from the edges equal to 5 per cent. of the width of the screen.

This proposed international standard agrees closely with British Standard 1404, 1953, which requires that the luminance of the screen at its centre, measured from any seat in the auditorium, shall not be less than 8 ft.-lamberts and not more than 16 ft.-lamberts, and that the luminance at the edges of the screen measured on a horizontal axis passing through the centre of the screen shall be between 0.6 and 0.75 times the measured luminance at the centre and shall preferably be as near as practicable to 0.7.

The conditions under which these measurements are taken are :—

(i) The projector and arc are running under normal operating conditions, with no film in the gate.

(ii) The optical system is aligned so that the area of maximum luminance is at the centre of the screen.

(iii) The lighting in the auditorium shall be that normally used when a film is being projected.

This British Standard was determined as a result of a large number of subjective tests of skilled and experienced observers, viewing normal release prints of various densities and contrasts of both colour and black-and-white subjects.

The observations of the viewers were listed under the following headings :—

(1) Visibility of grain.

(2) Appearance of flicker.

(3) Incidence of glare.

(4) Specific comments on individual subjects.

(5) General quality of projection (luminance).

The observations of 1, 2 and 5 plotted against log. brightness of screen in candles/sq. ft. are shown in Figs. 1 and 2.

In 1953, the 20th Century Fox Film Corporation of America introduced the CinemaScope technique of cinematography which involves the use of an anamorphic

The author is with the Cinematograph Exhibitors' Association. The manuscript of this paper was received on March 7, 1956. The paper was presented at a meeting of the Society held in London on April 10, 1956.

* Following the decision of the International Electrotechnical Commission, it was agreed to adopt the international unit of luminance, the "nit."

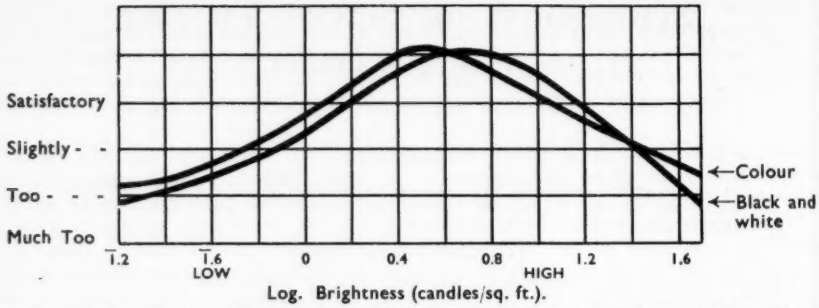


Fig. 1. The general quality of black-and-white and colour films plotted against log. of screen brightness.

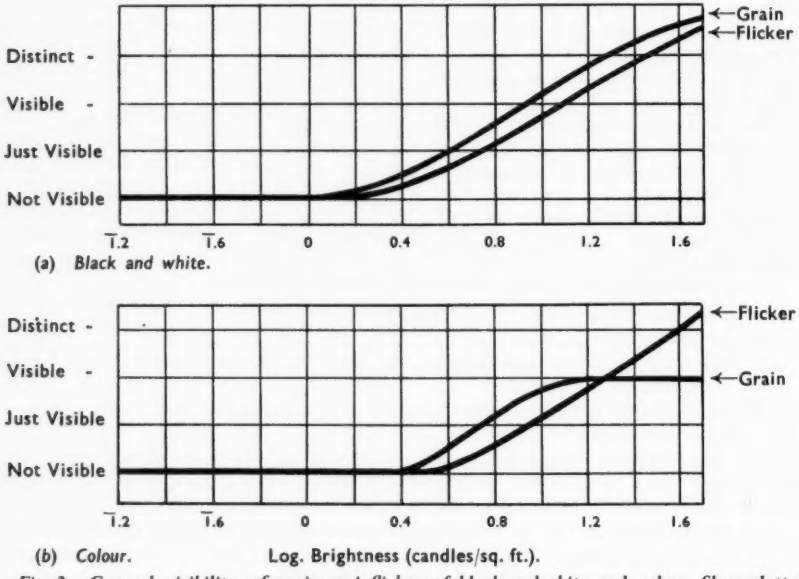


Fig. 2. General visibility of grain and flicker of black-and-white and colour films plotted against log. of screen brightness.

attachment to the camera lens which laterally compresses the photographic image falling upon the negative. A substantially similar anamorphic attachment must be used during projection to expand the photographic image to its proper proportions. This system provides a screen picture having a width-to-height proportion of 2.55:1,† compared with the previous standard ratio of 1.375:1. Initially, both negative and positive images were on 35 mm. film stock, but recently the negatives have been made on 55 mm. stock.

Also in 1953, the Paramount Film Corporation of America introduced the Vista-

† This proportion is reduced to 2.35:1 where an optical recording of the sound track is used.

Table 1.

Aspect ratio (width to height)	Illumination	Reduction per cent.	Gain in illumination required to maintain screen luminance
By reduction of aperture			
1.33:1	100	—	1
1.66:1	64	36	1.56
1.75:1	58	42	1.72
1.85:1	52	48	1.92
2:1	44	56	2.27
By use of anamorphic lens			
2:1	67	33	1.49
2.55:1	50	50	2.00

Vision system, which, whilst using a large negative format, provides by reduction printing, a 35 mm. positive release print with a photographic image having an aspect ratio of 1.85:1.

With the introduction of these two systems, it became the fashion to project "wide-screen" motion pictures and in most cases films of normal format were projected at any aspect ratio between 1.5:1 and 2:1, merely by fitting to the projectors aperture plates having a reduced height of aperture and using projector lens of shorter focal length in order to provide the same height of screen picture.

These systems involve a serious loss in screen luminance. It will readily be seen that where the height of the aperture has been reduced to provide a greater aspect ratio and a shorter focal-length lens has been used to maintain the same height of screen picture, the incident light falling upon the screen will be proportional to the square of the decrease in focal length of the lens.

Table 1 shows the reduction in illumination of screens having a constant height and the required gain in illumination to maintain screen luminance at its previous level.

Of the means available for increasing screen luminance, only that of brightness gain will be considered.

A perfect diffuser is one that gives 100 per cent. reflectivity and diffuses light in accordance with Lambert's Law, i.e., the intensity of light reflected in any direction is proportional to the cosine of the angle that direction makes with the normal to the surface. The matte white screens formerly in general use in cinemas closely follow Lambert's Law and have a reflectivity of 75 to 80 per cent. when new.

Surfaces which do not follow Lambert's Law and which appear to be brighter when viewed from some directions than from others, may be termed *directional* surfaces.

Upon the introduction of wide-screen motion picture techniques, screens having a directional reflection pattern have been used to obtain brightness gain. Law and Maloff have defined *brightness gain* as the ratio of the brightness of a given surface viewed from a given angle to that of a perfect diffuser viewed from the same angle with the same direction and quantity of illumination. A reflection pattern of a directional screen is shown in Fig. 3. Where the pattern has a circular cross-section in any plane normal to the direction of specular reflection, the reflection pattern may be said to be symmetrical; where the cross-section is not circular, the reflection pattern may be said to be asymmetrical.

A directional screen installed in a wide auditorium can result in unsatisfactory conditions of screen luminance for members of the audience sitting towards the

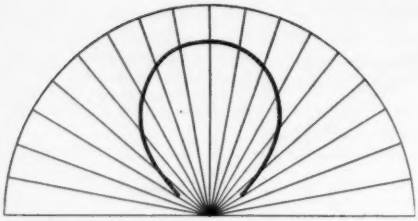


Fig. 3. The reflection pattern of a typical cinema screen having an aluminised surface.

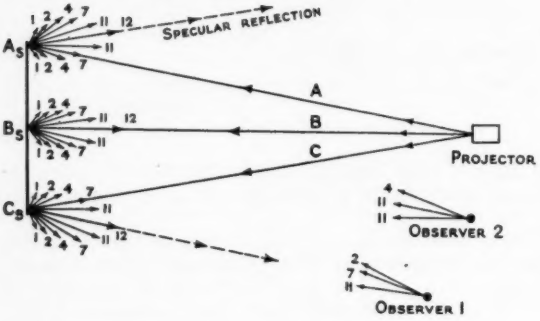


Fig. 4. Showing the lack of uniformity in screen luminance seen by two observers due to the use of a flat screen having an aluminised surface.

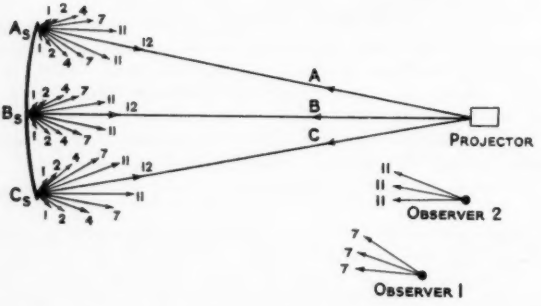


Fig. 5. Showing how the screen luminance becomes uniform to the two observers by the use of a curved screen.

sides of the auditorium. In Fig. 4 is shown a flat directional screen having a gain of 2.5. The reflection pattern of the projector rays A, B and C are shown at A_s, B_s and C_s. To an observer at (1) the luminance of these points of light will be 11, 7 and 2 ft-lamberts respectively, and such a wide lateral variance ($5\frac{1}{2}$ to 1) of screen luminance would be regarded as unsatisfactory.

To obtain a more uniform luminance, the screen may be curved as shown in Fig. 5. Here observer (1) will see points A_s, B_s and C_s at equal intensities. It is obvious that the radius of the curvature of the screen is dependent upon :—

(i) Reflection pattern of the screen ;
(ii) Focal length of projector lens ;
(iii) Distance of front and rear seats from the screen ;
(iv) Width of seating area ;
(v) Acceptable distortion of projected picture.

The curvature of the screen surface causes a distortion of the picture and may,

in some cases, result in a visible lack of sharp focus. Thus, there must be a compromise between distortion, resolution and uniformity of luminance.

Where directional and symmetrical screens are used, it is frequently necessary to tilt the screen to obtain a better distribution of light in the seating area.

Most directive screens are made of a plastic or fabric base upon which is sprayed a metallic element, usually aluminium. The reflection pattern is dependent upon the nature of the surface of the base, the thickness of the metallic coating, the size of the metallic grains and the viscosity and volatility of the vehicle used for spraying; by a suitable control of these factors, brightness gains of 1.5 to 4.0 can be obtained.

These directional screens depend upon random refractive or reflective scatter of light by microscopic metallic granules or surface irregularities, and their reflection patterns may be regarded as optical probability curves.

Dr. Hill, of the Motion Picture Research Establishment, has produced a simple and fairly accurate cosine approximation for these probability curves. His empirical formula :—

$$G_v = G_o \cos^n V$$

where $n = 2 (G_o - 1)$

G_v = gain at viewing angle V

and the relationship between G_o and n must be such as to satisfy the condition that all the light is distributed. The formula gives somewhat inflated values at small viewing angles and too low values at greater viewing angles, but is fairly accurate at angles between 35 and 45 deg.

To obtain controlled diffusion, it is necessary to provide not random scattering, but controlled direction of the reflected light.

During the last few years, considerable experimental work has been carried out with the view to obtaining more satisfactory reflection patterns, whilst maintaining high gain.

A small but highly efficient screen has been constructed of polished aluminium sheet, having regular indentations pressed into it, each indentation forming a small, concave mirror. The light falling upon each mirror is brought to a focus just in front of the screen and the aperture of each mirror depends upon the pitch and radius of curvature of the indentations. The horizontal and vertical pitches of the indentations differ and are determined to give reflection patterns closely approximating the seating pattern of the audience.

Many factors preclude the use of screens of this type, but the system has been closely approximated by the use of ribbed and "square-waffle" patterned fabrics which have received an aluminium vapour-coated surface. These surfaces generally show higher reflectivity values than aluminium painted or sprayed surfaces.

A screen of American design comprises a thin metallized plastic film supported by a fabric base. By passing the plastic film over rollers, a repetitive design is impressed upon the film, each element of which forms an optical element. The size of each element is 0.050 inches by 0.025 inches, which is sufficiently small that it cannot be resolved by the human eye at normal viewing distances. A serious drawback of this screen lies in the fact that the width of the imprinting roller is limited, and hence cinema screens must be built up of a number of panels. The seams are readily noticeable, particularly when a few weeks' dust has settled on the screen surface.

A recent experimental screen has been constructed of a transparent plastic material with rolled ribs on both its surfaces, those on the front surface being disposed horizontally and those on the rear vertically. The rear surface is silvered. The shape and size of the ribbing are the design factors determining the reflection pattern.

A difficulty experienced in the use of patterned screen surfaces is the creation of

moiré patterns arising from the superposition of one regular pattern upon another. Cinema screens are perforated with a uniform pattern of holes for the transmission of sound. and this pattern in conjunction with a uniform pattern of optical elements can produce disconcerting moiré patterns particularly when a motion picture is projected.

(2) Viewing Conditions

The correct distance at which any photographic reproduction should be viewed is given by—

$$D = f_c m$$

where

D = viewing distance.

f_c = focal length of camera lens.

m = magnification of photographic negative to produce positive reproduction.

Hitherto, for normal studio work, a camera lens of 3-in. focal length may be taken as an average, which gives an angle of 22 deg. subtending the eye of the observer sitting at the correct viewing distance. The normal range of viewing distances for commercial cinemas has been from 0.42D at the front seats to 1.83D at the rear.

The new wide-screen techniques have involved the use of camera lenses of shorter focal length, and, in some techniques, the use of larger negative formats. Hence, the correct viewing distances have decreased and angles of the picture subtending the viewer's eye have increased from 22 deg. for the standard format to 52 deg. for VistaVision films (at 1.85 : 1 aspect ratio) and 68 deg. for CinemaScope films (at 2.55 : 1 aspect ratio).

No major change can be made in the seating pattern of existing cinemas, and thus, the range of viewing distances has become 0.65D to 3.25D in the case of VistaVision and 0.77D to 3.8D in the case of CinemaScope. The " centre of gravity " of the area of " good viewing distance " has moved towards the screen.

In order that the quality of the projected picture be maintained, this closer approach to the screen has involved, in addition to the demand for greater accuracy and precision in camera and projector mechanisms, the necessity for higher quality of photographic image, the principal considerations of which are resolution and granularity.

A photographic image when enlarged is seen to be composed of a large number of small elements of silver of various shapes and sizes in a random pattern. The effect of scattered grains and particularly their apparent clumping, is visible at relatively small degrees of magnification. Apart from the grain pattern produced by the distribution of grains in any one horizontal plane, the total patterns produced not only by the overlapping of all these single planes at varying depths in the emulsion but also the successive frame by frame superimposition of grain patterns, must be considered.

The granularity of a photographic emulsion is approximately correlated to its sensitivity, the more sensitive the emulsion, the greater the granularity and the coarser the grains. For economic and other reasons, film producers demand high-speed or highly sensitive negative film stock, particularly for interior work in studios. For the positive release prints, slow speed emulsions having fine grains and low granularity may be used and it will, therefore, be recognised that the graininess of the motion picture viewed on the screen is more dependent upon the granularity of the negative than on that of the positive material.

Where the specialised wide screen techniques are used, a larger negative print is adopted and the positive print is obtained by reduction printing. By this process

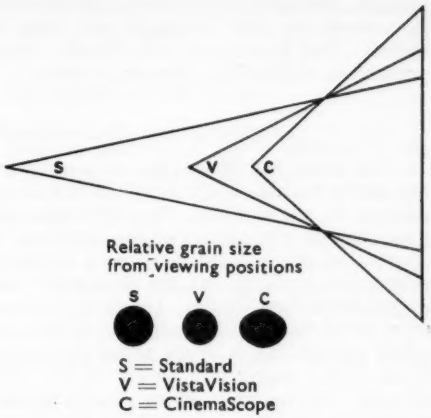


Fig. 6. Showing the relative grain size of the photographic image seen by observers seated at the "correct viewing distance from the screen."

the graininess of the negative is proportionately reduced. It has been shown that with the standard 35 mm. negative and positive format (0.825 in. × 0.600 in.) when a given material is used, at an appropriate magnification, the area of the mean grain pattern is 63.58 sq. units. (Arbitrary units are adopted, since the grain pattern size is dependent upon the nature of the negative and positive emulsion, the density and gamma to which they are processed and the degree of magnification of the image.)

In the VistaVision system, where the negative image is 1.475 in. × 0.977 in. and the positive is obtained by a 48 per cent. reduction printing, the visual grain pattern is reduced to 36.58 sq. units. With the new CinemaScope process where a 55 mm. negative is reduced to a 35 mm. negative, the grain pattern size is reduced to 48.32 sq. units. (Fig. 6.)

It will be appreciated from the foregoing that although the wide-screen techniques require a closer approach to the screen for "correct viewing," the photographic quality of the projected picture has been much improved.

(2) The Viewing of Television Screens

By R. D. NIXON, B.Sc., A.Inst.P.

Summary

The paper discusses the available contrast ratio on television screens of the aluminised and non-aluminised types, and indicates the reduction in contrast due to direct illumination of the dark portions of the picture by the bright portions, halation in the glass envelope and external illumination. The results show that picture contrast ratio may be reduced by these effects from about 150 : 1 under the best conditions to 25 : 1 under typical domestic viewing conditions.

Experiments in television picture viewing with illuminated surrounds are described and curves given relating picture luminance with the surround luminance giving greatest viewing comfort for three sizes of surround.

Television reproducers at the present time divide naturally into two groups, the directly viewed cathode ray tube and the projection arrangement in which an image on a small cathode ray tube is either front or rear projected on to a viewing screen. The characteristics of projection reproducers are in some ways similar to those of cine projectors, although, since the image source is a cathode ray tube screen rather

Communication from the Staff of the Research Laboratories of The General Electric Company, Limited, Wembley, England. The manuscript of this paper was received on January 11, 1956. The paper was presented at a meeting of the Society held in London on April 10, 1956.

than an illuminated transparency, the shortcomings of the projected picture caused by the cathode ray tube limitations are added to the distortions produced by the optical system. This paper deals with directly viewed tubes, which provide by far the larger proportion of television viewing screens.

(1) Mechanical Characteristics of Cathode Ray Tubes

The shape and dimensions of a current production type of cathode ray tube bulb are shown in Fig. 1. The bulb is the 21-in. rectangular type having screen dimensions of 51 cm. x 42 cm. It is evacuated and sealed up during manufacture, and the total force on the surface of the complete tube due to atmospheric pressure is about six tons, of which about two tons is applied to the screen face. It is clear that if the screen were perfectly flat, the glass would have to be of a very considerable thickness to withstand these forces. The screen is therefore made as a spherical surface having an external radius of curvature of 84 cm. (35 in.) and an internal radius of curvature of 69 cm. (27 in.), with the result that the plane through the centre of the screen is 5 cm. (2 in.) nearer to a viewer on the tube axis than the plane through the screen corners. The thickness of the glass in the screen centre is about 0.8 cm. (5/16 in.) increasing to about 1.6 cm. (5/8 in.) at the corners.

The luminescent screen itself consists of a thin layer of phosphor crystals which emit light when energised by the cathode ray beam. The layer may be applied to the inside of the screen surface by a number of methods, of which "settling" is at present the most popular. The bulb is supported with the screen down and filled to a depth of some 4 inches with water containing a small quantity of potassium silicate and an electrolyte (e.g. sodium sulphate). An appropriate quantity of phosphor suspended in a further chemical solution is sprayed on to the surface of the liquid in the bulb and the phosphor particles settle under gravity on to the screen face in about 20 minutes. The bulb is slowly tipped to decant the liquid without disturbing the phosphor layer, which is then dried. The potassium silicate reacts in a complex manner to form an adhesive layer binding the phosphor to the glass.

A screen made in this way can be, and often is, used in the tube without further

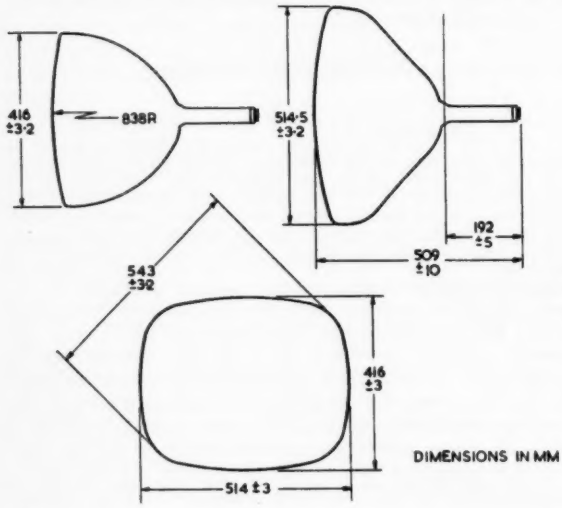


Fig. 1. Diagram of 21-inch 90-degree scan cathode ray tube.

processing. Considerable advantages in screen performance, however, may be obtained by the technique of "aluminising" which is described later.

(2) Performance and Limitations of the Screen

(2.1) Luminance Range and Contrast

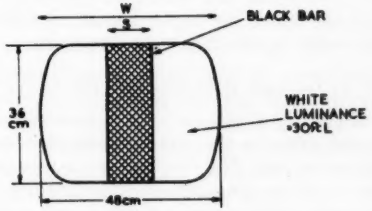
If a cathode ray tube with a screen made as described above is operated in the dark with a plain raster on the screen, the luminance range available goes from zero when no beam current flows to the screen, to a maximum limit set by the electron gun of the cathode ray tube (or more probably by the television receiver circuits) which may be about 100 ft.-lambert. This range corresponds, however, to the case of a cinema screen operating firstly with the projector lamp switched off and secondly with the lamp on and no film in the gate, and does not, of course, give any impression of the conditions available when a picture is reproduced. The range of luminance which may be achieved in a picture is controlled mainly by three factors :—

(1) Direct illumination of the dark portions of the picture by light from the bright portions.
(2) Internal reflections in the glass of the screen.
(3) External illumination.

These may be considered separately.

(2.1.1) *Direct Illumination*

Direct illumination of the dark portions of the picture by light from the bright portions is possible because the surface of the screen is curved and the screen itself is translucent. Flattening the screen would reduce the magnitude of the effect, but



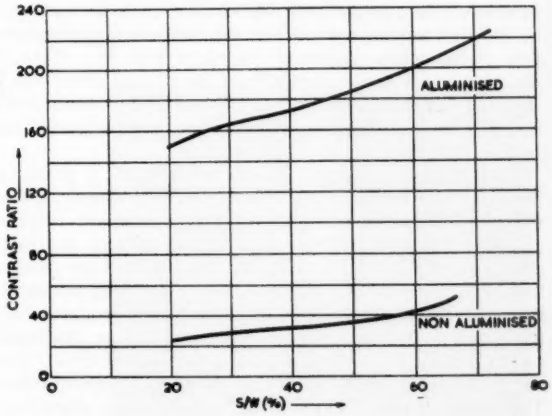


Fig. 2. Large-area contrast on aluminised and non-aluminised cathode ray tube screens.

there would still be difficulty with light reflected back to the screen from the inside surfaces of the conical part of the bulb. The alternative is to produce a backing to the screen which is substantially opaque to light but permits free passage of the exciting electrons. This may be achieved by providing a thin continuous film of a metal (aluminium is commonly used) over the inside surface of the screen, a technique known as "aluminising." The metal is deposited by evaporating a small pellet of aluminium from a hot filament inside the bulb which is evacuated before evaporation. A necessary preliminary to this process is to provide a continuous "filler" film of some nitrocellulose type of material over the phosphor screen, as direct evaporation on to the phosphor crystals does not produce an aluminium layer in the form of a continuous sheet. The filler film is subsequently removed by baking.

The aluminising process has two advantages besides the one under discussion: firstly the light output from the screen is approximately doubled, because the aluminium layer reflects towards the viewer light which would in a non-aluminised tube be radiated into the bulb, and secondly the technique gives complete protection from the two forms of ion burn which produce local reductions of the light output from the screen, particularly in the centre.

Measurements of the significance of the effect of direct cross-illumination were made by producing on an aluminised and a non-aluminised cathode ray tube a black strip of variable width on a white background, as shown in Fig. 2. The electrical pulse producing this black strip was arranged to cut off the beam current in the tube completely, and the measurements were made in the dark so that the only light on the black strip came from the bright areas on either side. The black strip was arranged to have a minimum width of 10 cm., so that the effects of internal reflections in the glass, as described in the next section below, did not affect the measurements.

The results are shown in Figure 2. Aluminising the tube increases the available contrast under the experimental conditions by a factor of five or six, depending on the width of the strip, and represents a substantial improvement in picture quality.

(2.1.2) *Internal Reflections in the Glass of the Screen*

The thick glass of the screen face results in a luminance distortion of closely spaced areas in the picture somewhat analogous to internal reflection effects in projection lenses. The mechanism of this phenomenon may be explained by reference to Fig. 3. If the phosphor particles are not in optical contact with the glass of the screen, the results of internal reflection and scatter in the glass are as shown in Fig. 3a and produce a circular area of diffuse illumination round the bombarded spot.

With complete optical contact between phosphor and glass, a total internal reflection phenomenon occurs as shown in Fig. 3b. Rays striking the outside surface of the glass at an angle greater than the critical angle (i.e., rays further from the normal than ray AB in the figure) are reflected back to the screen and scattered in the thickness of the phosphor, resulting in one or more bright annuli surrounding the spot, in addition to a diffuse disc.

In most cathode ray tube screens there is partial optical contact and an intermediate state between (a) and (b) exists. A typical halation pattern is that in Fig. 4 showing the diffuse bright area and the bright ring.

The effect of halation is to reduce picture contrast in closely spaced areas. It may be minimised by making the face of the tube of light-absorbing glass so that light travelling to the viewer directly from the screen passes through the glass once, whereas the light reflected back into the tube which produces halation passes through the glass three times and suffers a much larger relative attenuation. The transmission of the screen is normally arranged to be about 66 per cent. Measurements of halation luminance on screens made of clear glass and of "neutral-filter" glass are shown in Fig. 5. They were made on aluminised tubes in the apparatus used for the measurements

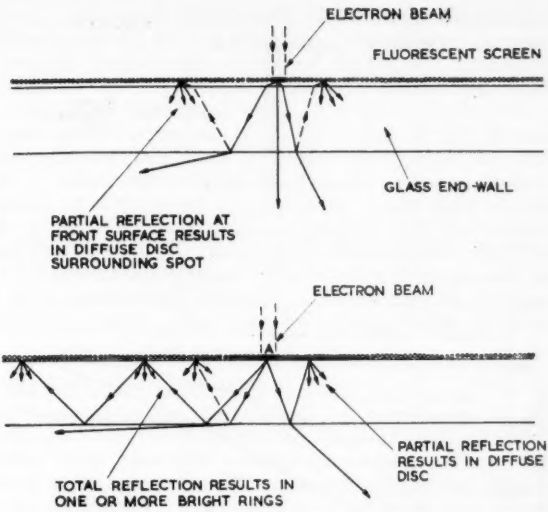

ELECTRON BEAM
FLUORESCENT SCREEN
(a)
GLASS END-WALL
PARTIAL REFLECTION AT FRONT SURFACE RESULTS IN DIFFUSE DISC SURROUNDING SPOT
ELECTRON BEAM
(b)
PARTIAL REFLECTION RESULTS IN DIFFUSE DISC
TOTAL REFLECTION RESULTS IN ONE OR MORE BRIGHT RINGS

Fig. 3. Mechanism of halation. (a) No optical contact between screen and glass. (b) Complete optical contact between screen and glass.

shown in Fig. 2, but the width of the black bar was reduced so that the effects of halation became apparent. It will be seen that the contrast between white and small black areas (less than 10 per cent. of the screen width) is improved by a factor of about 1.5.

(2.1.3.) *External Illumination*

The major difficulty in the satisfactory reproduction of gradations in a domestic television picture, especially in the lower tones, is the effect of external illumination. This difficulty need not arise in the cinema, where the ambient illumination is under the control of cinema designers and operators, but the majority of domestic lighting arrangements are not designed to give optimum conditions for television viewing. The measurements of contrast in the two preceding sections indicate that under the worst conditions (i.e. a picture which is substantially full white, with limited black areas) an aluminised cathode ray tube with a neutral-filter face plate can give contrasts of 200:1 between large areas and 40:1 between closely spaced areas. The

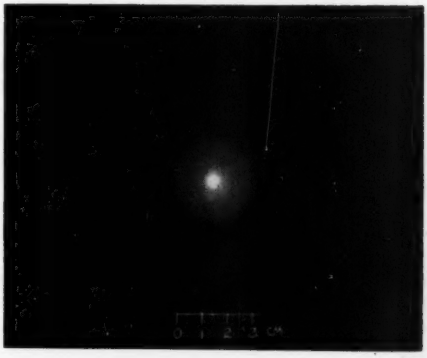
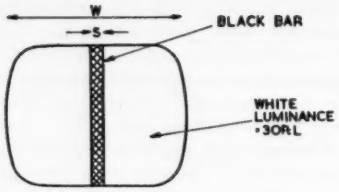


Fig. 4. A typical halation pattern.



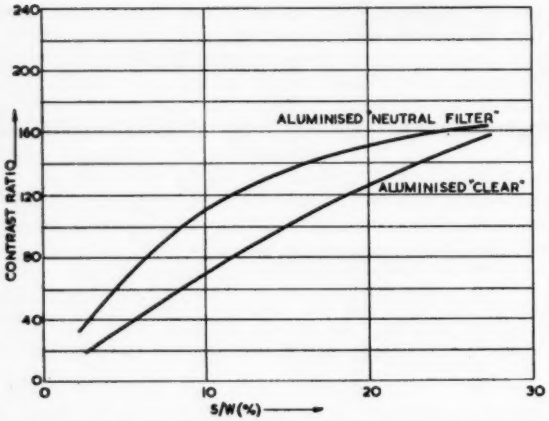


Fig. 5. Small-area contrast on 'neutral filter' and 'clear' aluminised cathode ray tube screens.

luminances of the " black " areas in these conditions are about 0.15 and 0.75 ft.-lamberts respectively when the tube is operating with a peak white luminance of 30 ft.-lamberts which is likely to be the upper limit for domestic viewing. The use of the neutral-filter face plate reduces the effect of the external illumination, since the external light passes through the glass twice, and the light from the picture only once. It will be appreciated, however, that the neutral-filter face plate reduces the maximum luminance obtained from the tube, and if any phosphor were available with a low reflectance (a black powder instead of a white) its use would give better results, from the point of view both of halation and external illumination. Transparent phosphor screens, where the fluorescent layer is formed directly on the glass by chemical deposition, would have similar virtues to a black powder, but the conversion efficiency of screens made in this way appears at present to be rather low.[1]

In an aluminised tube, the aluminium layer reflects forward some of the light from external sources which passes through the phosphor layer, with the result that the total screen reflectance of an aluminised tube is slightly higher than that of a non-aluminise tube. The screen luminances due to a given amount of external illumination are in the ratio of about 5 : 4. For the same reason, halation effects should be slightly more pronounced in the aluminised tube, but in practice the difference is swamped by the cross-illumination effects.

The direction and intensity of the source of external illumination on the screen of a domestic television receiver may clearly cover a very wide range, and no measurements could be expected for a general case. An attempt was made to provide an indication of the effect of a typical artificial light source, representing a normal domestic pendant fitting containing tungsten lamps totalling 150 watts and situated 8 ft. horizontally in front of the tube face and 5 ft. vertically above it. The luminances of

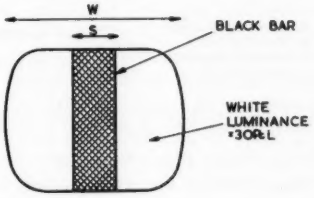
the screen of aluminised and non-aluminised tubes due to the external illumination under these conditions were found to be 1.0 and 0.8 ft.-lamberts respectively. A table lamp containing a 100-watt tungsten lamp placed on top of the receiver containing the tubes resulted in screen luminances of 0.15 and 0.12 ft.-lamberts respectively. Both measurements were made in a room with light-toned walls.

The measurements described so far were made with the screen of the cathode ray tube exposed. It is necessary to provide a safety glass screen in front of the tube in domestic receivers in order to protect the viewer in the event of a tube implosion. The safety screen usually consists of a flat sheet of glass about 6 mm. thick spaced about 1 cm. from the surface of the tube. This effectively provides a further source of external illumination since light from the brighter parts of the picture can fall on the dark areas by reflection from the safety glass. The effect is demonstrated in Fig. 6 where measurements on an aluminised tube with a black strip on a white ground are given with and without a safety glass screen for various widths of black strip.

(3) Sum of Degradation

The effects of all the sources of contrast degradation are summarised in the measurements of Fig. 7. Results are given for an aluminised and for a non-aluminised tube, each with a "neutral-filter" face plate and a safety glass screen. They were obtained by adding the luminances due to external illumination from the two lighting arrangements described above to the "black" luminances obtained from the contrast measurements.

The "centre fitting" viewing condition (represented by curves 2 and 2a of Fig. 7)



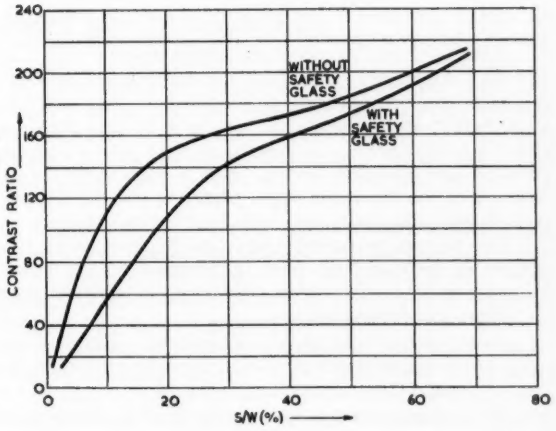


Fig. 6. Contrast on aluminised cathode ray tube screen with and without safety glass.

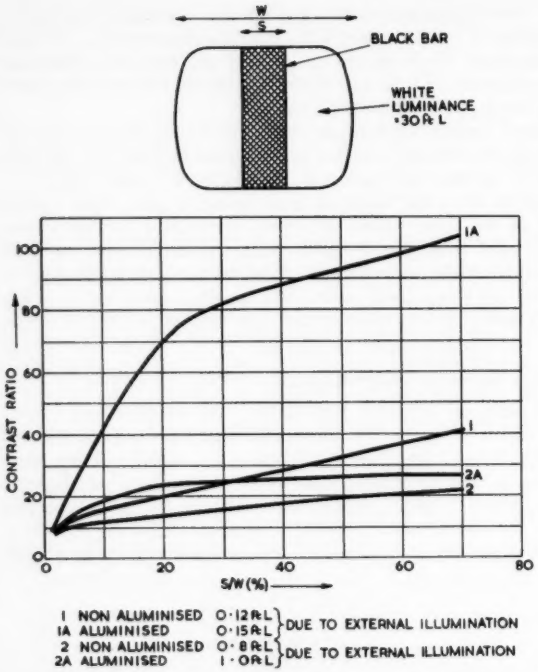


Fig. 7. Contrast on 'neutral filter' aluminised and non-aluminised cathode ray tube screens with safety glass and external illumination.

which is probably very common for domestic television receivers, reduces the mean contrast ratio of an aluminised tube from about 150 : 1 (Fig. 2) to about 25 : 1 and cancels to a large extent the improvement in contrast which is obtained by aluminising the tube, although the 2 : 1 increase in available luminance represents an advantage which has not been taken into account in computing the curves.

(4) Optimum Viewing Conditions

Since television receivers are viewed under a very wide range of lighting conditions and since the majority of viewers are presumably satisfied with the pictures they obtain, it is clear that the accurate reproduction on the television screen of the gradation of scene before the camera does not form a very large part of the average television viewer's requirements. It is probable that once a television receiver is so constructed, installed and adjusted that it gives a picture reasonably similar to that which an observer of the live scene might expect to see, the television viewer is more concerned, even if only subconsciously, with his viewing comfort.

The factors governing areas and luminances in the visual field to give various degrees of comfort have been investigated by Petherbridge and Hopkinson[2] and a summary of the main conclusions referred to television screen viewing has been stated[3].

These conclusions are:—

(1) That the field of view should be constituted as shown in Fig. 8, where the television screen A should have an immediate surround B and a general surround C.

(2) A should always be brighter than B, which should be brighter than C.

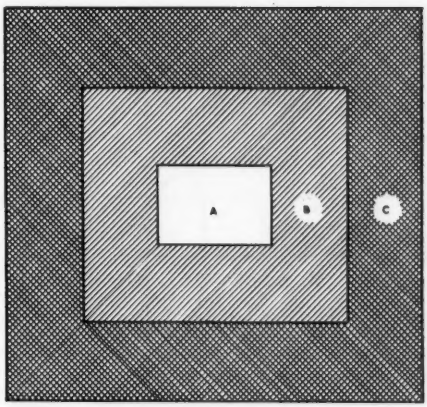


Fig. 8. Field of view for best visual comfort.

(3) The solid angular subtense of B should be not less than three times the subtense of A.

(4) The average luminance of the three areas A, B, C should be approximately in the ratio 100 : 10 : 1, although there is a wide range about these values which gives satisfactory visual comfort.

Experiments on the viewing of cinema screens with illuminated immediate and general surrounds have been described by Guth(4), who found that the general surround luminance had little effect on the required immediate surround luminance provided that it is lower than the latter. These measurements were made for only one angular subtense of the immediate surround, and the value of the subtense is not stated. The conclusion drawn from the experiments is that the required immediate surround luminance is approximately one-half of the square root of the average picture luminance.

Further experiments on the viewing of television screens with illuminated surrounds are described below.

(5) Experimental Arrangement

The experimental arrangement is shown in Fig. 9. The cathode ray tube screen, having a picture size of 43 cm. × 32 cm., was viewed through an aperture in an illuminated screen which was so positioned that light from the illuminating lamps did not fall on the picture. The viewing distance was 200 cm., giving a horizontal viewing angle of approximately 12 deg.

No provision was made for illuminating the general surround, but the light from the immediate surround maintained the general surround luminance level at approximately that suggested in section 4 above (i.e., about 0.1 of the immediate surround luminance). Three sizes of surround screen were used in the experiments. The dimensions and viewing angles are shown in Fig. 10. Six observers were used in the experiments.

The observers were asked to view a picture on the television screen and adjust the luminance of the surround until they found the viewing conditions for maximum comfort. Stationary and moving pictures were used. The observations were made for various values of peak luminance in the television picture, from 10 to 80 ft.-lamberts.

The average ratio between peak and mean luminance was found from a series of measurements made on a range of transmitted television pictures. In the interests of efficient transmission, most televised pictures explore the full luminance range from "black" to peak white, so that it may be assumed that very few pictures do not contain at least a small area which reaches peak white. A television receiver was adjusted

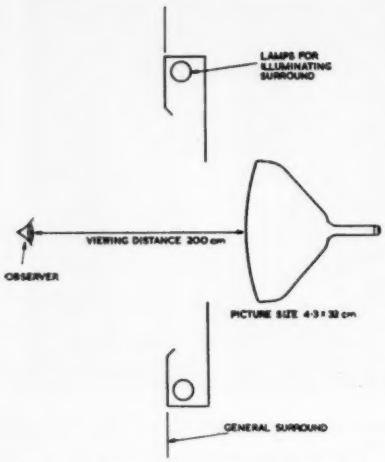


Fig. 9 (above). Experimental set-up for illuminated surround.

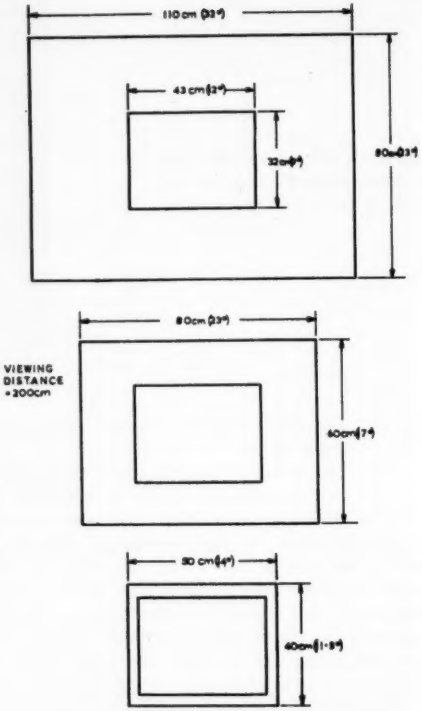


Fig. 10 (right). Sizes and subtended angles of surround screens used in illuminated surround experiment.

so that the peak white luminance was 20 ft.-lamberts, and the mean current in the cathode ray beam was recorded at short intervals during the picture transmissions. The value of beam current corresponding to 20 ft.-lamberts was measured on the tube, and by assuming a linear law connecting current and luminance, a sufficiently accurate assumption for this purpose, the mean luminance was estimated. Typical results for eight hours of varied transmission are plotted in frequency diagram form in Fig. 11. The modal value of these and other results gives a value of 3.3 : 1 for the peak to mean luminance.

The results of the surround-luminance experiments are shown in Fig. 12. The screen luminance/surround luminance relationships were found to be somewhat non-linear, with the smallest surround requiring highest luminance. Results from Guth's empirical formula[4] are shown as open circles and agree fairly well for the large surround at the lower luminances. There is a tendency for higher picture luminances to require proportionally higher surround luminances, which is in general agreement with the more critical experiments of Petherbridge and Hopkinson[2]. The observers were all of the opinion that the larger sizes of surround produced a marked improvement. The small surround contributed little to viewing comfort except for mean picture luminances below about 10 ft.-lamberts.

A useful improvement in viewing comfort could be obtained by operating television receivers with large-area illuminated surrounds. There are several objections to providing such devices, however, of which the most important would be economic and domestic. It is not usually possible to build illuminated surrounds of a usefully

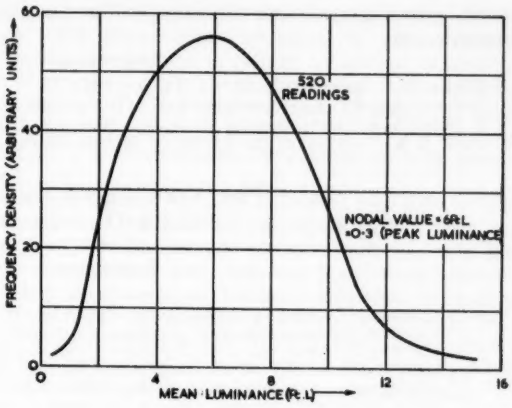


Fig. 11. Mean television picture luminance for peak luminance of 20 foot-lamberts.

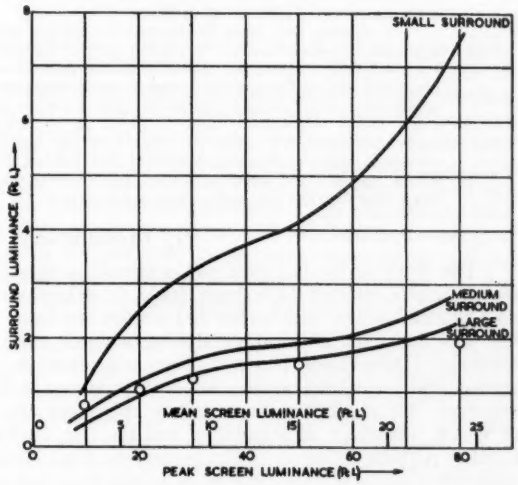


Fig. 12. Results of illuminated surround experiments.

large size into the restricted frontal area of modern receivers, and any increase in cabinet size not only increases costs to a marked degree, but would tend to make a receiver an unacceptable piece of furniture. The provision of folding surrounds would undoubtedly be resisted by both manufacturers and viewers, and since, as suggested above, the majority of viewers have established their own conditions with which they are apparently satisfied, the foregoing experiments are probably of academic interest only. Even in the cinema, where the desirability of illuminated surrounds has long been accepted and where the problems of providing them seem easier than in the domestic television receiver, very few have been installed. As far as the television viewer is concerned, the less light he allows to fall upon his screen and the more nearly he can approach, by adjusting his normal lighting arrangements, the " illuminated sur-

round" viewing conditions, the better will be his picture and the greater his viewing comfort.

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(3) The Viewing of Radar Screens

By S. T. HENDERSON, M.A., Ph.D. *(Member).*

Summary

Information on the positions of aircraft is commonly presented on a cathode ray tube as a circular plan centred on the observation point. Radial scanning produces successive images at short intervals, and from these traces the direction and speed of the aircraft can be estimated. The fluorescent screens are usually of the magnesium fluoride type with long exponential afterglow, and to avoid loss of detail the observations have formerly been made, either with no other light in the room, or with light of a colour more or less complementary to that of the screen; these conditions are inconvenient especially if other operations have to be done in the same room, such as aircraft control at airports.

A system has been developed by which ambient light of near-white appearance, good colour rendering properties and reasonable intensity can be used without loss of visibility in the cathode-ray tube presentation. A combination of fluorescent lamps is used covering almost the whole visible spectrum apart from a band in the region where the cathode-ray tube screen itself emits. A colour filter in front of the cathode-ray tube passes the screen emission but absorbs that from the lamps, so that a minimum of external light reaches the screen. The perfect combination of lamps and filters has not yet been achieved, but several versions of the system have been investigated and some used successfully.

(1) Introduction

The work to be described had originally a very limited objective. Applications of the principles evolved have been made to different radar installations, but only one kind of cathode-ray tube screen and display has been studied. The author's approach has been from the physical standpoint, without much regard for the visual processes involved. These have, however, been considered by some of the other parties concerned, and a workable system has been produced with marked advantages over earlier attempts. Of the others interested in this work the chief were the Radio Division of R.A.E. (Ministry of Supply)(1), and the Air Traffic Control Experimental Unit at London Airport (Ministry of Transport and Civil Aviation)(2). Differing requirements have led to considerable differences in the final installations, while other possible improvements are still being examined.

(2) The Problem

The problem is to provide lighting in rooms where radar screens are viewed without serious reduction of the visibility of traces on the screen. The purpose is partly to avoid the strain of working in almost dark surroundings and partly to allow of other activities in the same room such as plotting on maps and the paper work involved in control of aircraft. Reasonable colour rendering of the ambient illumination is desirable for these latter operations as well as for the general comfort of those working in the room.

The radar displays in question are of P.P.I. type on cathode-ray tubes with screens

The author is with Thorn Electrical Industries Ltd. The manuscript of this paper was first received on January 11, 1956 and in revised form on February 13, 1956. The paper was presented at a meeting of the Society held in London on April 10, 1956.

of magnesium zinc fluoride activated by manganese. These have orange-yellow fluorescence and phosphorescence. The decay after excitation is approximately exponential, so that each trace, indicating the position in plan of an aircraft, is initially very bright with a rapid decay. It is necessary that several previous traces of very much lower luminance should also be visible to the observer, since their spacing gives information on the speed and direction of flight of the aircraft. Usually the rotation speed of the transmitting aerial is from 4 to 15 r.p.m. and the cathode-ray tube screen traces recur at the same frequency.

The first attempt to provide ambient lighting seems to have used blue light, which could be produced by gelatine or similar filters over the lighting fittings or over the windows by day, with an orange filter over the cathode-ray tube screen to pass the light of the fluorescence but not the ambient blue, thus preserving high screen contrast. This scheme was worked out in detail[2] in spite of the usual difficulties of finding suitable filters and their imperfectly sharp cut-off. Incidentally it may be remarked that maximum objective screen contrast does not necessarily give the best viewing conditions, and the relative sensitivities and adaptations of fovea and peripheral retina will affect the situation; but in what follows the physical aspects alone are discussed.

(3) "White Minus Amber" Lighting

(3.1) Early Developments

The phosphor emission in the cathode-ray tube screen is a band of wavelengths with its peak near 5,950 Å falling to half peak intensity at roughly 5,700 and 6,300 Å. If the tube is provided with an orange-yellow filter then the principle of blue lighting described above can be extended to the use of near-white light, provided that this contains no wavelength in the band passed by the cathode-ray tube filter. Fluorescent lamps offer the widest selection of varied spectral emissions, but all normal types emit the mercury line spectrum including the yellow pair at 5,770 and 5,791 Å which are undesirable since they fall within the usual transmission band of the cathode-ray tube filter and the emission band of the cathode-ray tube screen. The problem then reduces to finding a suitable combination among the available lamps, with filters to cut out unwanted spectral regions. Most phosphor emissions, like filter transmissions, do not show a sharp cut-off anywhere in the spectrum; consequently any solution is necessarily a compromise.

At the time of the author's first contact with the problem a possible light source was available; it had been investigated for quite different reasons. Incandescent (tungsten) light had been colour-matched by a mixture of blue, green and pink fluorescent lamps; also by the same combination, in different proportions, but with the green and yellow emission of the pink lamp severely cut by an external red filter. The colour-rendering properties of the three sources were the original interest[3], but the last-mentioned combination, having a marked trough in its spectral emission between 5,500 and 6,000 Å, provided the starting point for the present work. Instead of the external red filter, ordinary commercial lamps with an internal red filter coat of cadmium selenide were used; the phosphor in the lamp is calcium silicate phosphor activated by manganese and lead, with peak emission at 6,400 Å. The other lamps were also standard types: green with zinc silicate phosphor activated by manganese (peak emission 5,250 Å), and blue with a calcium tungstate phosphor (peak emission 4,200 Å).

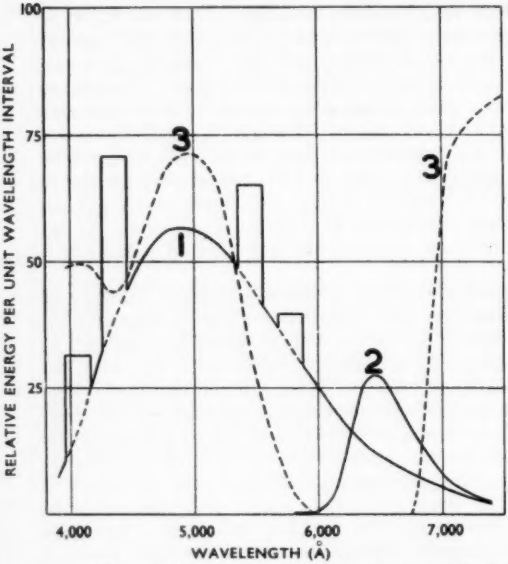
This combination of three lamps showed that the scheme was workable, that the radar observer could tolerate an appreciable amount of the ambient light falling on the filter in front of his cathode-ray tube screen. Certain difficulties arose and have needed much attention, namely (a) the adjustment of output levels of different coloured lamps (e.g., by dimming) to get the correct balance, (b) the provision of adequate light mixture in the fitting or by reflection from a ceiling, to avoid colour fringing, and (c) the avoidance of the possibility of seeing illuminated objects in the

room, and, in particular, the observer's own face, reflected from the cathode-ray tube filter surface. (The design and siting of the fittings is important for the efficiency of the method, but is not dealt with in this paper.) A more fundamental trouble was the yellow mercury line emission in the blue and green lamps (the filter coat on the red lamp removes it almost completely). This unwanted yellow emission was almost eliminated by suitable blue filters on the lamps. The next step was to replace the blue and green lamps by a single one in the interests of simplicity. The phosphor chosen was barium titanium phosphate[4], which gives high efficiency, good maintenance and a wide emission band extending throughout the visible spectrum; another advantage was that when filtered appropriately, one lamp together with two red lamps gave a reasonable "white" without dimming the output of any of the three.

(3.2) Filters

The external filters used for lamp correction were made from thin sheets of coloured plastic and referred to by standard code numbers; the sheets were made into cylinders slipped over the lamps. For the bluish-white barium titanium phosphate lamp the filter was No. 16, blue-green. Its transmission is shown in Fig. 1, curve 3. Curve 1 of this figure gives the spectral energy distribution of the bluish-white lamp, and curve 2 that of the red filter-coated lamp on the same energy scale.

Fig. 2 shows the emission of the phosphor screen (curve 1) and the transmission of the plastic filter used in front of the cathode-ray tube (curve 2). The filter originally



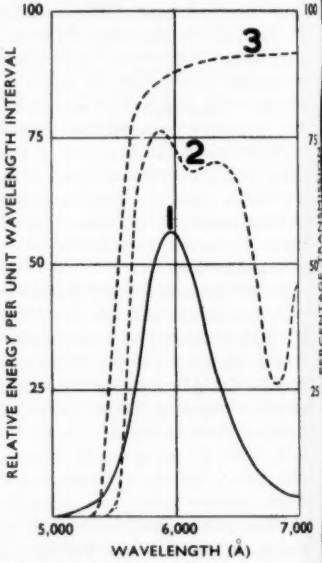


Fig. 1 (left). Curve 1. Spectral energy distribution of bluish-white lamp (type 1001).
Curve 2. Spectral energy distribution of filter-coated red lamp.
Curve 3. Transmission curve of No. 16 filter (blue green).

In curves 1 and 2, mercury lines are shown as bands 200Å wide; the two lamps are shown on the same energy scale.

Fig. 2 (right). Curve 1. Spectral energy distribution of cathode-ray tube screen.
Curve 2. Transmission of No. 559/8 cathode ray tube filter.
Curve 3. Transmission of No. 300 cathode-ray tube filter.

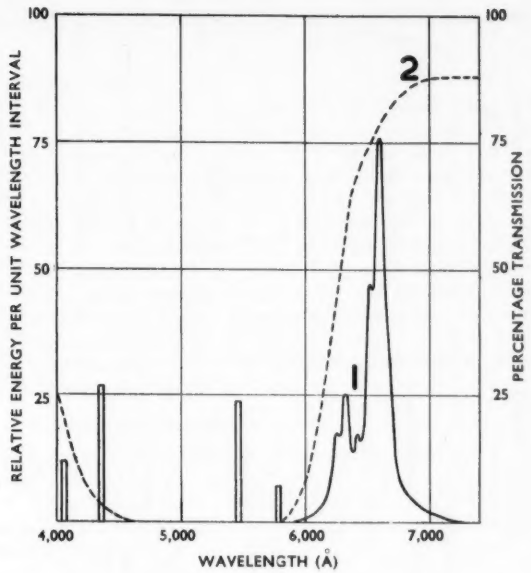


Fig. 3. Curve 1. Spectral energy distribution of red germanate lamp (type 1301). Mercury lines are shown as bands 40Å wide.
Curve 2. Transmission of No. 14 filter (ruby).

used (No. 300) is shown in curve 3; it had a similar steep rise near 5,500 Å, but no additional red absorption band. The more complicated filter[5] was developed as a further refinement, of particular interest in connection with later improvements of the light source (see 3.3).

It should be mentioned that the work on cathode-ray tube filters was a separate project in which the author of this paper was not concerned.

(3.3) Later Developments of the Light Source

Figs. 1 and 2 indicate that the short wave-length side of the "amber gap" in the ambient lighting is fairly well defined, especially when it is remembered that the cathode-ray tube filter attenuates incident light twice before it re-emerges to the eye; the long wave-length side is, however, not entirely satisfactory. Though low in visual efficiency, the red emission from the lamp could pass freely through the original cathode-ray tube filter, and fairly well through the modified one, with degradation of the dark cathode-ray tube screen background.

Since the cathode-ray tube filter represented the best that could be done at the time in transmitting orange but cutting red wave-lengths, it was desirable to shift the red lamp emission to longer wave-lengths, preferably to 6,800 Å to coincide with the red absorption band (about 25 per cent. transmission at 6,800 Å, or 6 per cent. after two transmissions). No entirely suitable lamp phosphors are known, and it was necessary to use manganese-activated magnesium arsenate or germanate, which in the fluorescent lamp emit an unusually narrow series of bands, remarkably similar for the two phosphors, and having a sharp peak close to 6,600 Å.

A full-scale test was conducted with magnesium arsenate lamps, a filter No. 14 (Fig. 3, curve 2) being used to remove mercury lines. Two red to one bluish-white lamp (barium titanium phosphate) were used in fittings facing the ceiling, whereby an illumination level of the order of 5 lm/ft² was attained at the working plane. The radar screens, carefully arranged to avoid reflections in their external filters, were under a

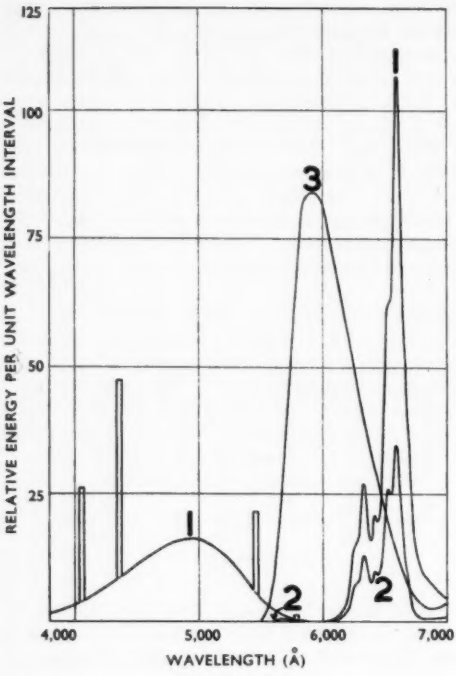


Fig. 4. Curve 1. Spectral energy distribution of light from type 1001 lamp with No. 16 filter, plus type 1301 lamp with No. 14 filter. Mercury lines are shown as bands 40Å. wide.

Curve 2. Spectral energy distribution of above as modified by two transmissions through No. 559/8 filter.

Curve 3. Spectral energy distribution of cathode-ray tube screen as modified by transmission through No. 559/8 filter. Energy scale different from that of curves 1 and 2.

much higher illumination than that conventionally considered a maximum (0.1 lm/ft²), but were nevertheless operated without loss of efficiency.

Lamps using magnesium arsenate alone as a phosphor were found to have a somewhat poor lumen maintenance compared with other types. Magnesium germanate has a better performance though extremely expensive; this type of lamp is now considered to give the best performance with existing filters. Other phosphors of the same general type are known, but are unsuitable for various reasons. Fig. 3 shows the germanate emission spectrum (curve 1) and the absorption curve of the filter used with it (No. 14, ruby). Fig. 4 shows in curve 1 the output of the combined filtered lamps (one of each), and the effect of the cathode-ray tube filter on this light (curve 2) and on the cathode-ray tube screen emission (curve 3). The very high energy peak of the unfiltered red lamp is noticeable, but this corresponds to relatively little visual effect on account of its deep red colour. Even when filtered there is a fairly large amount of residual energy in the red, suggesting that a better cathode-ray tube filter is desirable.* One lamp of each kind is probably a better mixture than one bluish-white with two red, as recent trials with germanate lamps have shown. The two main emission peaks in Fig. 4 (curve 1) may vary relatively to some extent according to the lamp efficiencies.

The colour rendering properties of the combined light source are good, except that the yellow deficiency causes yellow objects to appear dull or pale, and orange objects to appear red. Complexions appear to be sunburnt (not tanned).

The system using arsenate lamps was tested operationally by the R.A.F. in 1954,

* When this paper was read before the Society it was possible to demonstrate an improved filter (No. 99/55). Similar to that shown in curve 2 of Fig. 2, but with its red absorption band centred near 6,500 Å.

and it is expected that the germanate lamp combination will be adopted in future for certain types of installation.

(3.4) Modified System in Use at London Airport

With the number of lighting fittings available, the system described in para. 3.3 did not provide a sufficient level of illumination for the particular requirements of the Air Traffic Control Centre at London Airport where, in a single room, there is a combination of procedural control (i.e., planning the flow of traffic) with radar control (i.e., location and direct control of individual aircraft). This was because the flight progress boards used in procedural control need to be illuminated to as much as 20 lm/ft^2. Owing to the distance of the radar screens from the flight progress boards it was found possible to permit a certain amount of yellow light to remain without lowering seriously the contrast on the radar screens. As a result, the desired lighting conditions were obtained by a combination of two filter-coated red lamps (3.1 and Fig. 1 curve 2) to one bluish-white lamp without filter, which gave a rather more natural working light than the more completely yellow-deficient light described earlier. This system has been in operational use since April, 1955.

Acknowledgments

The lighting system described has been developed in collaboration with Mr. C. R. Barnard of R.A.E., Mr. J. Noyes and Mr. J. W. Birchall of A.T.C.E.U. The filters described were made by I.C.I. Ltd., Kodak Ltd., British Celanese Ltd., and B.X. Plastics Ltd. The author is indebted to the directors of Thorn Electrical Industries, Ltd., for permission to publish this paper.

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Discussion

DR. W. J. WELLWOOD FERGUSON: I would like to add my congratulations to the three authors for the most interesting papers we have just listened to. The facts have been stated so plainly that I have little comment to make. I feel that there is room for some development in screen surround lighting in cinemas, perhaps with some increase in the level of lighting in the auditorium, both of which would add to the comfort of the audience and could be achieved without marring the performance in any way.

I would like to ask whether the modern television set is fitted with a neutral filter and, if so, whether this is incorporated in the safety screen or in the glass of the tube itself.

The problem of suitable illumination for the viewing of radar screens is a fascinating one. I am sure it is one which will call for still more ingenuity from the lighting engineer.

MR. H. C. WESTON: Few people who have enjoyed seeing wide-screen cinema pictures realise how much consideration has had to be given to the design of screens, so as to avoid the loss of luminance which would otherwise have occurred with the new projection systems. As Dr. Knopp has pointed out, the new techniques have brought the correct viewing distances nearer to the screen, and so the angle of elevation of the picture for people in the best seats has increased where no change in the height of the picture has been made. This matter of angle of elevation is

one with which the I.E.S. Committee on Eyestrain in Cinemas has been much concerned quite recently. No doubt when new cinemas are planned they will be designed to allow the best viewing conditions for wide pictures. Dr. Knopp has not mentioned illuminated picture surrounds or the level of illumination in the auditorium. Both of these matters were studied before the war, and I wonder if Dr. Knopp can say anything about more recent work.

As to the viewing of television pictures, I have had occasion to make some experiments on the permissible amount of room lighting and, with modern receivers, full domestic lighting is satisfactory providing the light sources are suitably placed. The graduation of surround brightness for comfortable viewing does not appear to be very critical. Providing stray light reaching the screen does not make the picture contrast ratio less than about 25:1 the pictures seem to be generally acceptable.

The lighting engineer is sometimes asked to do the impossible in the lighting of radar rooms. I admire the ingenuity of the system described by Dr. Henderson, but, having seen it in operation, I am disappointed with the results as far as the general appearance of the room is concerned. The great problem in radar rooms is that of preventing the formation of bright images of room surfaces at the surface of the displays. I have suggested a system of low level lighting for ships' radar compartments. This illuminates the floor adequately but allows no direct light and little reflected light to reach the displays. Trials of this system have so far proved satisfactory.

MR. S. ANDERSON: I agree that the pleasure of viewing television is improved if the ambient brightness near the set is fairly low, but I do not find any disadvantage in having the intensity of light at the viewer considerably higher than that in the vicinity of the screen; this enables me to read the programme or other literature in comfort.

In view of the importance of a suitable surround brightness, it would be an improvement if TV sets provided this by means of a lamp of, say, 15 watts mounted in the back of the set, to shed some light on the wall behind. Alternatively, sets with doors might have the inner surfaces of these finished white instead of the usual dark polished wood. I believe many sets still have the neutral filter incorporated in the implosion screen, thus forfeiting the advantages described by the author in reducing internal reflections in the glass of the cathode ray tube face.

During the war I believe a type of cathode ray display known as the "Skiatron" was used to avoid the difficulties associated with radar traces visible only in very low ambient illumination. I would like to know why, in tackling the present problem of radar room illumination, a high brightness display, bright enough to be visible in ordinary room lighting, is not used.

MR. F. P. BENTHAM: As a theatre man my interest lies in the first two papers. I cannot help wondering from whom the desire for extra auditorium lighting to lessen eye strain comes. Surely a large proportion of the cinema audience prefers the dark, though possibly not for reasons connected with screen viewing.

I am sure the proper approach is a light surround which could nevertheless be separated from the screen by the narrow black border necessary to cope with projection imperfections. Such a surround could be designed to pick up the necessary level and colour of light from the scatter from the screen itself. It would be on the lines of a device I used in my ardent viewing days before the war. A funnel whose four sides each made an angle of roughly 45 deg. to the plane of the screen was constructed in white cardboard and propped against the front of the television set. This funnel picked up the scatter from the screen and automatically gave a

level appropriate to the scene going on. Curiously the relative area surround to screen was more or less what is called for in to-day's paper.

The light coloured cabinet doors suggested by Mr. Anderson would form an effective substitute for the vertical sides, the horizontal top and bottom could rest on ledges on the doors and fold away equally readily. Using a gadget like this it is possible to view in the dark or near dark and give the attention due to a masterpiece such as "1984." Room lighting can all too easily lead to background viewing, which is even worse than background listening. To get the best out of the best television demands concentration similar to that needed in the theatre, where the darkened auditorium has always been the rule.

MR. J. G. HOLMES: I am interested to see that the wider screens described by Dr. Knopp might subtend an angle of as much as 90 deg. and that with an aspect ratio of 1.75:1 this would correspond to a vertical angle of rather more than 50 deg. I understand that this is bad practice and invite Dr. Knopp's comments.

Referring to Dr. Henderson's paper, the complementary lighting system employed during the war was generally found to be quite unsatisfactory. The requirement for that system was that factory lights should not be visible from the air, and extensive experiments were made on the combination of yellow light from sodium lamps and a blue/green window glass which did not transmit this yellow light. The result was a sickly green during the day and a sickly yellow at night, and the system was not adopted for more than a few experimental installations. Dr. Henderson's present use of complementary lighting, however, is a much more elegant arrangement because he has been able to find a greatly improved yellow filter which transmits the orange light from the cathode ray tube, but little else. The ambient light is a combination of unsaturated red and blue, which is likely to be acceptable to those working under it and permit reasonable recognition of coloured materials. In the Approach Control Room at London Airport provision has been made for light sources of this type, but they have not been working satisfactorily. I hope that Dr. Henderson's proposals will enable this installation to be brought into use.

MR. PHELPS: I do not agree that low contrast in television pictures is acceptable to viewers. Full advantage should be taken of the range of contrast that is available. Though the eye is a tolerant organ, it should not be abused.

MR. A. H. WILLOUGHBY: Dr. Knopp has explained lucidly the factors affecting the optimum viewing distance of cinema screens, and is obviously of the opinion that of these factors, perspective distortion is the most important.

Mr. Nixon did not touch on the subject of viewing distance. Would he be prepared to comment on whether these same factors affect the optimum viewing distance of a television screen, and which is the most important?

I would guess that resolution considerations outweigh all other factors. Assuming this to be so, I suggest that the optimum viewing point is at that distance at which the angle subtended by one scanned line at the viewer's eye is approximately equal to the resolution of the eye (i.e., approximately one minute of arc).

It has been said that when a picture of limited resolution is viewed at such a distance, it appears to contain more detail than is apparent on closer examination; the viewer's eye and brain use the experience of a lifetime to "see" familiar details which, in fact, are not present in the viewed picture. Thus, if the viewer moves from this optimum distance, towards the picture, the apparent resolution appears to fall off very rapidly.

If, indeed, the best viewing distance is mainly conditioned by these factors, then a 405 line television picture on a 14 inch cathode ray tube is best viewed at approxi-

mately 6½ ft. A 21 inch cathode ray tube is best viewed at approximately 10 ft., which distance would seem to be somewhat great for normal home viewing.

MR. K. R. ACKERMAN: The majority of television cameras have a limited contrast range of 30:1.

DR. KNOPP (in reply): Many promising experiments with illuminated screen surrounds were carried out in cinemas prior to the war. With the advent of wide screen motion pictures which almost completely fill proscenium openings, illuminated surrounds would, in general, require substantial structural alterations; these wide screen techniques involve the projection of pictures of varying widths and heights which would also entail constructional difficulties; furthermore, with the greater use of colour films, difficulty has been experienced with the provision of harmonious colour lighting for the surround.

An ingenious system was used at the Festival of Britain cinema. The rear surfaces of the projector shutter blades were polished and reflected the light passing through the projector aperture and the film via mirrors and masking plate on to the screen surround, thus providing an illumination of the surround by the "integrated" colour of the film being projected.

In reply to Dr. Wellwood Ferguson's observation, I think it is true to say that there is a general desire to increase the level of auditorium lighting when new installations are planned. There has recently been published an I.E.E./B.S. Code of Recommended Practice for Maintained Lighting in Cinemas which has been well received in the film industry.

Mr. Weston has been an active member of the I.E.S. Committee on Eyestrain in Cinemas, but I made no reference to the work of this Committee because its final report has not yet been published*, and I, therefore, regarded the matter as *sub judice*.

Mr. Holmes appears to assume that the lower edge of the screen is at, or above, eye level. This is not always so and, in any case, I do not think that as a generality one can accept a vertical angle to the top of the screen in excess of 50 deg. as being necessarily bad practice. The fact that a lesser limiting angle has been determined by the I.E.S. Committee on Eyestrain in Cinemas merely reflects current cinematographic practice, but provided the action field or the area of movement or interest in motion pictures is kept at a comparatively low level, it is immaterial how high the upper edge of the screen happens to be.

I am afraid that Mr. Willoughby credits me with opinions which I do not hold. There are many factors affecting the production and projection of motion pictures of a greater importance than perspective distortion; I endeavoured to show that whilst wide screen techniques required a closer approach to the screen, this had been made possible by the improved quality of photographic images.

MR. NIXON (in reply): In answer to Dr. Wellwood Ferguson, modern television receivers are almost invariably fitted with neutral filters, and this is usually incorporated in the glass of the cathode ray tube. Some receivers have neutral filter implosion screens in addition.

Mr. Weston's comment that pictures having contrast ratios of about 25:1 are acceptable is probably true, but I must agree with Mr. Phelps that this low limit should not be regarded as desirable. There is no doubt that more pleasing results are obtained by using the illuminated surround and by keeping contrast as high as possible.

The suggestion by Mr. Anderson that the inside of the television receiver doors,

* The Report of the Committee on Eyestrain in Cinemas has since been published in these Transactions Vol. 21, No. 7, pp. 168-177.

where these are fitted, should be finished white, is undoubtedly a good one, and we must hope that manufacturers will act on it. It is probable, however, that many television receivers sell on their merits as pleasing articles of furniture rather than as picture reproducers, and white paint on the screen surround might not be as acceptable as a nicely grained veneer. A folding surround as described by Mr. Bentham, although satisfactory for a viewer on the tube axis, gives an asymmetrical appearance for other viewing positions which may be somewhat distracting.

In answer to Mr. Willoughby's comments, both perspective distortion and line visibility may be used as criteria of the optimum viewing distance, although it is our experience that the eye is very tolerant of perspective distortion. These factors are discussed in some detail in Reference 3, and figures rather similar to Mr. Willoughby's are arrived at. A wide variation is permissible, and in particular visibility of the line structure on large tubes at less than the optimum viewing distance is not as important as might be supposed. It has been said somewhere that if the line structure on a 405 line picture is irritating at the viewing distance imposed by domestic limitations, it is a criticism of the picture content rather than of the television system itself.

DR. HENDERSON (in reply): I believe Mr. Weston saw the London Airport installation, which is a compromise attempting to satisfy at the same time requirements of widely differing character. The complete system described in Section 3.3 is much more satisfactory in operation and, as demonstrated at the meeting, still further improvements are being made. It would be very interesting to try the floor lighting system with the combination of special "Radar" fluorescent lamps.

My wartime recollection of the "Skiatron," mentioned by Mr. Anderson, are that the projected radar displays suffered seriously from lack of contrast between the blue-green (mercury discharge) background and the dark purplish traces produced in the potassium halide screens by the electron beam. The present position is that no conventional type of cathode-ray tube screen will give a trace visible for the required period at a brightness level comparable with ordinary room lighting.

With regard to Mr. Holmes's comments, I should perhaps make it clear that the Approach Control Room he mentioned is quite separate from the Southern Air Traffic Control Centre described in Section 3.4. The latter is concerned only with aircraft whilst they are moving between airports and not under local control.

Additions to the List of Members

The following applicants have been duly elected by the Council to membership in the Society and their names have been added to the list of members:—

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Printed by
ARGUS PRESS, LTD.,
Temple-avenue and
Tudor-street,
London, E.C.4.
England.